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Publication of the National Sigma Xi Lectures

POSSIBLY no activity of Sigma Xi has been more enthusiastically received than the National Sigma Xi Lectureships and their publication in book form. It has been felt for some time, however, that one more important step might be taken in an endeavor to secure a wider distribution of the lecture material to the great body of active and alumni members who have not heard the lectures nor had access to the two volumes of "Science in Progress." The plan adopted by the Executive Committee, on an experimental basis, involves the publication of each of the lectures in the QUARTERLY, one or two to an issue; the type to be held for later reprinting in book form. It is hoped that two objects will be achieved in this way: (1) the lecture material will be made available to a large percentage of the membership; (2) the expense of publication in book form will be reduced and, thereby, a wider distribution of the successive volumes of "Science in Progress" secured. The first lecture to be printed under this plan, "Image Formation by Electrons," Dr. V. K. Zworykin, appears on the following pages. It is expected that the remaining four lectures of the 1941 series will follow in succeeding issues of the QUARTERLY. Comments from the membership will be appreciated, and will be of great assistance to the Executive Committee in determining future decisions.

National Lectureships for 1942

THE FOLLOWING lecturers have been chosen for the 1942 National Lectureships. Detailed information will be sent to chapter secretaries during April. Requests from chapters are to be received by November 1st.

- H. A. Bethe, Cornell University—"Stellar Energy"—March 15-April 15.
- P. W. Bridgman, Harvard University—"Some Recent Work in the Field of High Pressures"—February 15-March 15.
- H. M. Evans, University of California—"Recent Work on the Anterior Pituitary"—May.
- J. G. Kirkwood, University of Chicago—"The Structure of Liquids"—March.
- L. S. Marks, Harvard University—"Modern Power Generation"—April.

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V. K. Zworykin

IMAGE FORMATION BY ELECTRONS

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THE rapidly widening field of applications of electrons, both in science and in everyday life, is an outstanding characteristic of the present century. One of the newest applications of electrons is for the formation of images much as light is used to form optical images. Electron images make possible the electron microscope, with which man can resolve objects at least fifty times smaller than can be seen with the best light microscope; they play a fundamental rôle in modern television; and find many other interesting and important uses. Indeed the importance of electron imaging has become so great as to give rise to a new branch of electronics known as electron optics.

An important part of designing an ordinary optical system for forming light images concerns itself with the direct or indirect determination of the paths of light rays through the various lenses. Similarly the determination and control of electron trajectories is the function of electron optics.

Early studies of the behavior of cathode ray beams under magnetic and electric fields revealed that these rays consisted of particles, later to become known as electrons, which had a fixed ratio of charge to mass, and that the paths could be completely determined by the laws of ordinary mechanics. It soon became evident that not only could these cathode rays be investigated by means of magnetic and electric fields, but also that the converse was true, and that cathode ray beams could be used to measure these fields. Thus, the first cathode ray oscillograph, or Braun's tube, came into being. With this tube, the magnitude of rapidly varying voltages applied across one pair of deflecting plates could be observed, if a linearly varying deflecting voltage was applied to the

other pair. The cathode ray beam in these tubes was generated by a low pressure gas discharge, and the ionized gas molecules in the tube kept the beam concentrated into a narrow bundle. A fluorescent screen on the end of the tube showed the position of the beam as a luminous spot.

A limitation to these tubes soon became apparent. As the rapidity of the variations in the voltage to be measured became greater, making necessary a higher deflection frequency for their observation, it was found that the gas ions which heretofore kept the beam in focus could no longer follow the rapid lateral motion of the beam, and the beam became diffuse.

This difficulty, together with other lesser objections to the Braun tube, led to the development of a tube in which the source of electrons for the cathode ray beam was a thermionic cathode, and coaxial cylinders or apertures were used to concentrate the beam. Instead of apertures and cylinder, it was also found that electromagnetic coils with their axes parallel to the beam could be equally well used for focusing.

While investigating these tubes, an interesting observation was made. It was found that by suitably adjusting the voltages on the concentrating electrodes, or on the magnetic focusing coils a clear, enlarged image of the thermionic cathode could be observed on the fluorescent viewing screen. These images, in fact, were frequently used to determine whether the activation of the cathode was uniform, and served as a convenient way of studying defects in the cathode. This tube can be called a forerunner of the electron microscope.

Towards the close of the nineteen twenties, the importance of electron imaging was beginning to be more apparent, and a good deal of theoretical work was being done to determine the nature of this phenomenon. In 1926 a paper was published by H. Busch, in which he showed there was a complete mathematical analogy between electron trajectories in a potential field and light rays in refractive media; furthermore, he showed that any cylindrically symmetrical electric or magnetic field was capable of forming a first order or Gaussian image. This paper was followed shortly by other theoretical

and experimental studies by Pict, Davisson, Knoll, and others, which showed not only the possibility, but also the general practicality of electron lenses. By 1932 an electron optics, based upon the analogy between light and electron motion, had become a clearly recognized field.

Once the foundations of this field had been established, progress was rapid, and practical applications followed almost immediately. The systematized knowledge of electron optics could be applied directly to the problem of building an electron gun which was capable of producing the high density—fine—cathode ray beam required in modern television and cathode ray tubes. The study of electron paths was applied to the problem of amplifier tubes, and led to the development of the beam power tube, the secondary emission multiplier, and other similar devices. At the same time, much work was done on extended electron images. It was found, for example, that sharp, undistorted, electron images could be reproduced from optical images focused on a photo-electric cathode. Another important application of electron imaging was in the electron microscope. The first compound microscope employing electrons as the imaging means was reported by Knoll and Ruska in 1932. The development of the electron microscope has progressed rapidly and today it has become a practical research tool, capable of resolving objects at least 50 times smaller than can be seen with the best optical instrument. Before giving a more detailed discussion of the principles of construction and application of the electron microscope, I would like to give a brief outline of the elements of electron optics, and the principles underlying electron image formation.

Broadly speaking, electron optics is the study of electron paths in electric or magnetic fields. In the design of any electron optical system, the aim is to determine the shape of the electrodes or magnetic coils which will cause electrons leaving a given point or group of points to reach certain other predetermined points. The problem stated thus has no general solution. Indeed, in all but the simplest cases, it cannot be solved at all. Instead it is necessary to invert the problem and

ask what electron trajectories are obtained from a given configuration of electrodes or coils. A systematic series of solutions of the latter can be used to answer the former.

The problem of determining electron trajectories from a given electrode system at known potentials can be divided into two parts. First, the potential distribution must be found from the form of the electrodes. Then the electron paths can be determined as the electrons move in this field. Similarly, when magnetic elements are involved, the field distribution produced by the coils, pole pieces, etc., must be calculated, and then the electron motion in these fields sought.

In any charge-free region, the electrostatic potential must be a solution of the Laplace differential equation, which in ordinary Cartesian coordinates, has the form:

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}=0$$

Furthermore, the solution is subject to boundary conditions such as to make the electrodes equipotential surfaces.

Ordinarily the electron optical systems encountered in practice do not require the solution of the general three-dimensional equation, because most practical systems have a rather high degree of symmetry. The two most common types of systems are those which may be termed two-dimensional, and those involving cylindrical symmetry. The Laplace equation for these two cases becomes:

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0 \quad \text{two-dimensional}$$

$$\frac{\partial^2\phi}{\partial z^2}+\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial\phi}{\partial r}=0 \quad \text{cylindrical symmetry}$$

Even with these simplifications, a mathematical solution of the equation is very difficult, and frequently can only be obtained through the application of approximate methods.

Fortunately, there is a relatively simple experimental method of measuring the potential distribution in an electrode system. The method consists of immersing an enlarged model

of the electrode system into an electrolytic bath, applying potentials which are proportional to the working potentials to the various members of the system, and by means of an exploring probe determining the potential distribution of the electrolyte. A space current j flows between the electrodes, which, because no charges accumulate, obeys the equation of continuity

$$\operatorname{div} \mathrm{j} = 0$$

Since the conduction in the electrolyte is ohmic, the field strength E is proportional to the current density, hence

$$\operatorname{div} \mathrm{E} = 0$$

Therefore, as $\mathrm{E} = -\operatorname{grad} \phi$, where ϕ is the potential; the potential distribution within the electrode system immersed in the electrolyte satisfies the Laplace equation, and corresponds to the distribution in the actual electrode system.

The typical electrolytic tank used for such measurements is metal lined for purposes of shielding, and is filled with a weak electrolyte—in fact usually ordinary tap water has enough dissolved salts to suffice. The exploring probe is carried on a pantograph which reproduces its motion at a marking stylus over the mapping board. The probe itself is a fine wire point held so that it just breaks the surface of the liquid, this being adequate for any electrode system having mirror symmetry which, as has already been pointed out, includes nearly all those which are of practical importance. When this symmetry is present it is only necessary to make a model of one of the two symmetrical halves of the electrode system. The model is inserted in the tank in such a way that the plane of symmetry coincides with the surface of the liquid. The desired distribution on the plane of symmetry is measured by the probe.

The probe is connected to a carefully calibrated potentiometer through a sensitive current detector which gives a null-indication when the potential of the probe equals that of the electrolyte. Potentiometers are also provided to supply the voltages to the electrodes. In order to avoid polarization effects at the electrodes, 400-cycle a.c. is used instead of direct current.

After the potential distribution has been found, either as a result of analysis or from electrolytic measurements, the next step is to determine electron trajectories. Here again, the mathematical difficulties become very great. Even when the function describing the potential is known, an exact solution of the paths is rarely possible, and approximate or graphical methods must be employed.

From a purely logical standpoint, the electron paths in a potential field could be determined from the Newtonian laws of mechanics in their ordinary form; however, it is generally more convenient to make use of them expressed as the principle of least action. Where electrostatic fields only are present, the path is defined by the following variational integral.

$$\delta \int_a^b \mathrm{p\,ds} = 0$$

where ds is an element of path length, and p is the momentum of the particle, and is given by

$$\mathrm{p} = \sqrt{2\mathrm{m\,e}\phi}$$

ϕ being the potential at points along the path. Eliminating the constant factor, the integral becomes

$$\delta \int_a^b \sqrt{\phi}\ \mathrm{ds} = 0$$

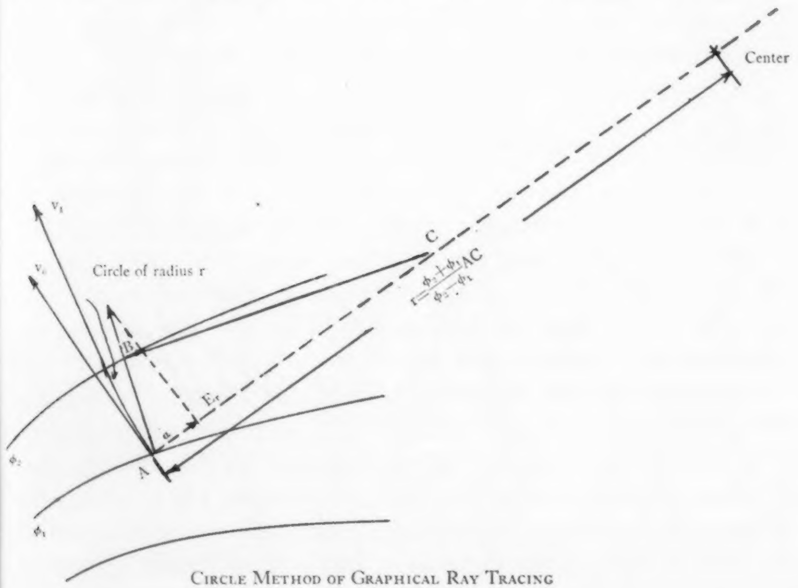
This integral shows clearly the mathematical analogy between electron paths and light rays, because it is identical in form with Fermat's theorem defining the path of a ray of light:

$$\delta \int_a^b \mathrm{nds} = 0$$

where n is the index of refraction of the medium along the ray. It will be seen that the square root of the potential plays exactly the same rôle in an electron optical system as does the index of refraction in an ordinary optical system. Where magnetic fields are present, the equivalent of an index of refraction for an electronic system can be found, but in

this case it is somewhat more complicated, the index being non-isotropic.

One of the simplest methods of plotting electron trajectories which is applicable to any system having mirror symmetry, is the graphical procedure usually termed the circle method. This method is based on the fact that the centripetal acceleration of an electron moving in a circular path must be balanced by a radial force, that is a radial field component. Referring to Figure 1 showing the map of a section of



CIRCLE METHOD OF GRAPHICAL RAY TRACING

FIG. 1

the potential field within an electrode system, assume now that an electron is moving through this field with a velocity as indicated by the vector v_o. This electron is acted on by a force e E where E is the field strength at the point it occupies. The force may be resolved into two components, one parallel to its direction of motion, the other e E_r at right angles to it. The normal component causes the electron to move in a circular path such that

$$\frac{v_o^2}{r} = \frac{eE_r}{m}$$

and since $$v_0 = \sqrt{\frac{2e\phi}{m}}$$

it follows that $$r = \frac{2\phi}{E_r}$$

Referring again to the slide, it is evident that

$$E_r = E \cos \alpha = \frac{\phi_2 - \phi_1}{A\,B} \cos \alpha = \frac{\phi_2 - \phi_1}{A\,C}$$

and consequently $$r = 2 \frac{\phi_1}{\phi_2 - \phi_1} A\,C$$

or, for greater accuracy $$r = \frac{\phi_2 + \phi_1}{\phi_2 - \phi_1} A\,C$$

The electron trajectory can, therefore, be approximated by a series of circular arcs between the successive equipotentials, the radii and centers of the arcs being obtained by a simple graphical construction indicated in Figure 1 based upon the relation just derived.

Determining the trajectories through electron lenses and the performance of such lenses is a special case of the general problem of electron path determination. As has already been pointed out, the electrodes serving as lenses are cylindrically symmetric, so that the electrolytic tank can be used to determine the potential distribution within them. The circle method can also be used to determine the electron paths through lenses; however, usually the care necessary to obtain the required accuracy does not warrant its application in view of other methods which take advantage of the high degree of symmetry.

The potential field where radial symmetry exists can be expressed as an expansion in terms of the potential distribution on the axis. With this expansion and the Euler form of the principle of least action, a differential equation can be set up which gives the electron path in terms of the axial distribution and its derivatives. This equation, which is termed the ray equation, has the following form:

$$\frac{d^2r}{dz^2} = \frac{r}{4\phi}\frac{d^2\phi}{dz^2}\left[1 + r^2\left\{\frac{1}{4\phi}\frac{d^2\phi}{dz^2} - \left(\frac{1}{8}\frac{d^4\phi}{dz^4}\bigg/\frac{d^2\phi}{dz^2}\right)\right\} + \left(\frac{dr}{dz}\right)^2 + \cdots\right]$$
$$-\frac{1}{2\phi}\frac{dr}{dz}\frac{d\phi}{dz}\left[1 + r^2\left\{\frac{1}{4\phi}\frac{d^2\phi}{dz^2} - \left(\frac{1}{4}\frac{d^3\phi}{dz^3}\bigg/\frac{d^2\phi}{dz^2}\right)\right\} + \left(\frac{dr}{dz}\right)^2 + \cdots\right]$$

When discussing the performance of a lens, two points are of interest. First, the position and magnification of the image. Second, the quality of the image, that is, its sharpness and freedom from distortion. The position and magnification of the lens are determined by its first order image properties, namely, its behavior for rays which make a very small angle with the optical axis. These characteristics are generally defined in terms of four cardinal points, namely, two focal points and two principal points. It might be pointed out that for an ordinary thin lens, the two principal points coincide at the lens, and thus the simple relation

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

between object distance u, image distance v, and the focal length f is obtained. Similarly, the magnification is given by

$$m = \frac{v}{u}$$

These concepts apply quite generally and, therefore, can be used to define the properties of electron lenses as well as optical lenses. Thus the problem of finding the first order properties of an electron lens involves locating the four cardinal points.

In making this determination, since only paraxial trajectories are involved, the ray equation reduces to

$$\frac{d^2v}{dz^2} + \frac{1}{2\phi}\frac{dv}{dz}\frac{\partial\phi}{\partial z} + \frac{1}{4\phi}\frac{\partial^2\phi}{\partial z^2}\, r = 0$$

With the aid of this equation, two rays are traced through the lens, for example, one parallel to the axis on the image side, the other parallel to the axis on the object side, and from these paths the cardinal points can be located.

In tracing electron rays through such systems, we are again faced with solving a rather difficult differential equation. In this brief discussion, time does not permit going into the various methods and short cuts that are helpful in carrying out the solution of specific problems. There is, however, one graphical procedure developed by Richard Gans, which I should like to discuss. A series of straight lines are substituted for the curve representing the true axial potential distribution, the number depending upon the accuracy required.

Consider now the ray equation; over any straight line segment the second derivative is zero. Hence, the ray equation becomes a simple differential which can be directly integrated twice to give

$$r = r_o + \frac{2C\,(\sqrt{\phi} - \sqrt{\phi_o})}{S}$$

where $C = \frac{}{dz}\sqrt{\phi}$, $S = \frac{d\phi}{dz}$ the slope of the segment,

and r_o ϕ_o are the radial position and potential at the beginning of the segment.

At the point where two segments join, there is a singularity, and $\frac{d^2\phi}{dz^2}$ is infinite. The ray equation can be integrated over the transition giving

$$\left(\frac{dr}{dz}\right)_2 - \left(\frac{dr}{dz}\right)_1 = -r\,\frac{S_2 - S_1}{4\phi}$$

Here subscripts 1 and 2 indicate values before and after the break point, respectively. Finally, where the segment is parallel to the axis, the solution becomes

$$r = r_o + \left(\frac{dr}{dz}\right)_o (z - z_o)$$

These three solutions are applied successively to the segments and break points, thus tracing the ray through the system.

So far we have dealt almost exclusively with the problem of electrostatic lenses. This is because the analytical treat-

ment of electrostatic systems is much simpler than that for the magnetic systems. For certain simple coil configurations, the magnetic field distribution may be determined analytically. Many of the coils used in practice, however, are sheathed in iron. The presence of iron greatly complicates the problem. If the iron enclosing the coil has a high permeability, and is operated well below the saturation point, the two poles may be considered as equipotentials of a scaler potential whose gradient is the magnetic field. Under these conditions, the potential distribution, and hence the field, may be determined with the aid of the electrolytic plotting tank. Where these methods cannot be applied, the magnetic distribution must be determined experimentally by means of exploring coils, by the change of resistance of such metals as bismuth or by the Hall effect.

The first order ray equation for a magnetic lens has the following form

$$\frac{\partial^2 r}{\partial z^2} = -\frac{eH^2}{8\, m\phi} r$$

The radius vector r does not remain in a plane as it does for the electrostatic case, but rather rotates about the axis. Therefore, it has the form

$$(r) \quad e^{i\theta} = x + iy$$

The angle θ is given by the integral

$$\theta = \left(\frac{e}{8\,m}\right)^{1/2} \int_{z_0}^{z} \frac{H}{\sqrt{\phi}}\, dz$$

Before leaving the discussion of the first order properties of electron lenses, it should be mentioned that for thin electric and magnetic lenses, that is, those for which the region of varying electrical potential or of magnetic field is small compared with the focal lengths, the principal points may be considered as coinciding at the lens, analogous to the thin optical lens, and the focal lengths will be given by the following integrals:

Electrostatic $$\frac{1}{f_i} = \frac{1}{8\phi_i^{1/2}} \int_{-\infty}^{\infty} \frac{1}{\phi^{3/2}} \frac{\phi'^{2}}{z} dz$$

$$\frac{f_i}{f_o} = \left\{\frac{\phi_i}{\phi_o}\right\}^{1/2}$$

(i denotes image side of lens)

Magnetic $$\frac{1}{f} = \frac{e}{8m\phi} \int_{-\infty}^{\infty} H^2 \, dz$$

The discussion given above has been restricted to the first order properties of electron lenses. From a practical standpoint, the perfection of the electron image is of equal or greater importance. The lens defects of electronic systems are quite analogous to those in light lenses. Considerations of the behavior of paraxial rays, with one exception, reveal nothing of the image defects of a given lens. In order to determine the aberrations, it is necessary to consider rays which make an appreciable angle with the axis of the system. Although it was not explicitly mentioned, first order imaging which gives the cardinal points, assumes that the trigonometric function describing the passage of the rays from the object point, through the lens, and to the image point, is expanded in a power series of r and that terms involving all but first powers of r can be neglected. The Seidel theory of aberrations includes the terms involving the third power of r. Second power terms vanish because of symmetry requirements. There are five aberrations on the basis of this theory. These are:

Spherical Aberration
Astigmatism
Coma
Curvature of the Image Field
Distortion

In addition, there is another image defect due to variations in the velocity of electrons. This defect is analogous to chro-

matic aberration in light systems, and is given the same name.

Let us examine these aberrations briefly.

Spherical aberration is due to rays passing through the outer parts of a lens, which do not converge on the paraxial image point. This aberration differs from the other four third order aberrations in that it affects points on the axis of the system.

Astigmatism occurs when rays from an object point, lying in a plane including the axis of this system, converge on a point which is different from that upon which rays lying in a plane normal to the axis converge.

Coma is the result of rays through different parts of the lens not meeting in a common image point, but differs from spherical aberration in that it vanishes for object points on the axis. Its name is derived from the comet-shaped area over which rays from an object point meet the image plane.

Curvature of the image field, as the name implies, means that image points from a plane object do not lie in a plane.

Distortion of the image is due to a non-uniformity of magnification or to a twist of the image.

The procedure for calculating these aberrations in an actual system is extremely difficult and laborious, and is beyond the scope of this discussion.

Most of these defects can be reduced, and some practically eliminated by a proper design of the electron optical system. Instead of attempting to describe general methods of dealing with these various aberrations, let us consider some of the practical applications of these lenses and discuss the aberrations as related to specific problems.

Applications of Electron Optics

The utility of a cathode ray tube, whether for use as an oscilloscope or for television purposes depends, as has already been pointed out, upon the ability to produce an extremely fine electron beam, having a relatively high current density. For this an electron optical system which is roughly analogous to an optical projection spotlight is required. The system which serves this function is usually termed the electron

gun. Guns used in modern tubes are almost universally made up with two lens elements. The first lens, that is, the lens nearest the cathode, is usually electrostatic, while the second lens may be either electrostatic or magnetic. The cathode is located at one extremity and is usually an indirectly heated oxide coated emitter. Immediately adjacent to the cathode is the first lens system, consisting of two apertured discs, one of which is the control grid governing the current in the beam, the other the first anode. This lens causes the electrons leaving the cathode to converge into a narrow bundle, called the cross-over. The cross-over is the point where the principal rays from the emitter meet the axis, and corresponds to the exit pupil of the analogous optical system.

The second lens generally used in the gun is also electrostatic, and is made up of the first and second anode cylinders. The potentials of these cylinders are so adjusted that the cross-over is imaged on the fluorescent screen, mosaic, or any other element of the tube, where the small spot is required.

It may seem surprising at first sight that a reduced image of the cathode is not formed on the screen but instead an image of the cross-over. However, it turns out that for a given spot size and lens, the maximum current density can be obtained by imaging the cross-over.

Since the second lens essentially focuses an image point on the axis into an object point the only third order lens defect which needs be considered is spherical aberration. This aberration acts, of course, to increase the spot size. By properly shaping the electrodes in an electrostatic gun, or the lens coil of a magnetic gun, it is possible to reduce this aberration. However, even with these corrections, it is necessary to place a limiting aperture near the second lens to mask off the outer part of the lens.

Two lens defects at the first lens make the cross-over larger than would be predicted from the first order theory. These are due to variations of initial velocities and to space charge effects. The former is related to the velocities of emission from the thermionic cathode. The second is due to the mutual repulsion between electrons where the charge density is high.

These defects place a limit on the current density and fineness of the cross-over.

The details of the construction of an electron gun depend, of course, upon the applications for which it is intended. A gun to be used in an Iconoscope for television pickup must be capable of producing a minute spot of only a few thousandths of an inch in its greatest dimension. However, the beam current is small—of the order of a tenth of a microampere or less. Furthermore, the sensitivity and shape of the control grid characteristic is unimportant. The gun is located in the long glass neck. Opposite the gun is the mosaic which is the photosensitive element which plays the fundamental rôle in converting a light image into a picture signal.

The gun used in the Kinescope or viewing tube is the same in principle as that in the Iconoscope. The requirements are, however, quite different. The current needed is much greater, being of the order of a milliampere. Against this the permissible spot diameter is larger. Since the picture is reproduced by varying the beam current as the spot sweeps across the fluorescent screen, the control characteristic of the grid is a matter of utmost importance.

Television projection Kinescopes, tubes reproducing pictures in sufficient brightness so that the image can be thrown on a large screen, employ guns which require perhaps the greatest engineering skill in their design. These guns must not only produce an extremely small spot, but must also be capable of delivering even more current than those of the ordinary Kinescope. In order to obtain the necessary brightness, the projection Kinescope is operated at very high voltages, that is, 50 to 70 kv. Although this introduces insulation, corona, and cold discharge problems, it makes the electron optical design somewhat simpler.

Another application of electron optics, which I would like to describe, represents a rather different type of imaging than occurs in the electron gun. This is the electron imaging system developed to increase the sensitivity of the Iconoscope. The scene to be televised is focused on a large semi-transparent photocathode. Electrons which leave the photosensitive

surface are distributed according to the intensity variations of the light image. An electron lens system refocuses these electrons into an electron image of the original scene. By allowing the electron image to fall on a mosaic which has a high secondary emission ratio so that for every photoelectron which strikes it several electrons leave, the sensitivity of the pickup tube can be increased.

The electron lens employed in this imaging device is based upon the potential distribution between two coaxial, equi-diameter cylinders. However, in order to overcome aberrations which would otherwise make the system unusable, it is necessary to modify the simple basic arrangement. Since the electron ray bundles passing through the lens are small, spherical aberration is negligible. Likewise coma, although present to a somewhat greater extent, is not great enough to constitute a limiting factor. The three third order aberrations, astigmatism, curvature of the image field and distortion, if not corrected, cause serious loss of detail and image perfection. Chromatic aberration also is a limiting factor.

I have reserved discussion of the electron microscope until last, because it is one of the newest and most interesting applications of electron optics. In principle this microscope is very similar to the conventional light microscope. Each microscope has a source of the radiation used for making observations, condenser lenses for concentrating the radiation onto the specimen, an objective lens which forms an enlarged first image of the specimen, and a projection lens which forms the final image. In the electron microscope the source of radiation is a thermionic cathode. Electrons from the source are accelerated to a high velocity as soon as they have left the cathode. The electron lens used in the electron microscope may be either electrostatic or magnetic, and comparable results have been obtained with both types of systems. However, so far most electron microscopes in use at present are equipped with magnetic lenses, chiefly because of certain practical considerations.

Let us consider first the imaging process by which the enlarged first image is obtained. An analysis of the physics

of image formation either with light or electrons shows that it is closely related to the phenomenon of diffraction, and consequently dependent upon the size of the object being imaged, the angular aperture *a* of the lens and the wavelength λ of the radiation employed. The expression which gives the size of the smallest detail which can be resolved is the following:

$$d = \frac{0.5\lambda}{\mu \sin a}$$

Since for visible light the smallest wavelength that can be used is in the neighborhood of 4000 Å, and the maximum index of refraction of the fluid immersing the object is 1.7, even if *sin a* is given its maximum value of unity, the smallest distinguishable distance is about 1200 Å.

Where high velocity electrons are used as the observing medium, the minimum distinguishable distance is very much smaller. The effective wavelength of electrons in motion is given by

$$\lambda = \sqrt{\frac{150}{V}} \text{ Angstrom Units}$$

where V is the electron velocity in volts, a relation which is derived from the wave mechanics of matter. Electron velocities of 60 kv or more are used in practical electron microscopes, and hence the effective wavelength is less than .05 Å or one-one hundred thousandth that of light. The angular aperture at the object is determined by the spherical aberration of the lens and, as will be explained later, the method of imaging. For objectives such as are used in present day electron microscopes, the aperture is of the order of one or two thousandths. Hence objects as small as 10 or 20 Å can theoretically be resolved. This is in close agreement with the observed performance of the modern electron microscope.

It was mentioned that the size of the objective aperture is related to the method of forming the image. In the conventional light microscope light passing through the specimen is absorbed in varying amounts at different points, and it is this variation in transmission that produces the differences

in intensity of light in the final image. The specimens used in an electron microscope are usually completely transparent so that all the electrons striking the object are transmitted through it. However, although electrons are not absorbed by the specimen, they are scattered, the amount of scattering at each point being a function of the density and thickness of the object. Electrons which are scattered through more than a certain predetermined angle are intercepted by the limiting aperture, therefore the electron density in the image will vary with the thickness and density. It will be evident from this that the contrast depends upon the size of the limiting aperture and that leaving aside all considerations of spherical aberration in the objective lens, a small aperture must be used if high contrast is to be obtained.

The electron projection lens, which forms the final image from the intermediate image, does not limit the attainable resolving power. The angular aperture of the electron ray bundles entering the projection lens is so small that spherical aberration effects in this element are entirely negligible.

The construction of the new RCA electron microscope is as follows: The cathode and gun is located at the very top of the instrument. Below it is the condenser lens, the objective, and the projection lens. The specimen is held in the object chamber, which will be described in some detail a little later. Finally, there is a fluorescent screen, pivoted in such a way that it can be moved into position to receive the electron image or rotated back so that photographic plates placed below it are exposed. The entire electron optical path is maintained at a pressure of about 10^{-5} mm. Hg. by an oil diffusion pump.

The power supplies for the overall microscope voltage and for the electron lens coils are located in the cabinet which forms the rear portion of the instrument. These power supplies require very careful design, since the slightest variation in overall voltage or in lens current tends to defocus the instrument. Special circuits are provided which hold the high voltage and the objective lens current to a constancy of one part in fifty thousand. The condenser and projection

lenses do not require quite as careful regulation, and are made constant to 0.02 per cent and 0.004 per cent, respectively. With this degree of stability, the electrical circuits impose no limitation on the resolving power even below 10 Å.

As has already been pointed out, the main body of the microscope is maintained at a high vacuum. Since the volume of the main chamber of the present microscope is rather large, if it were necessary to let air into the instrument each time a specimen is changed, considerable delay would be encountered. To avoid this, an air lock is provided at the object chamber, arranged so that the specimen can be moved into a small chamber which can be sealed off from the rest of the instrument. To remove the specimen, therefore, it is only necessary to let air into this small compartment. The new object is then placed in the chamber, the chamber evacuated, and the object moved into its place above the objective. The whole operation of changing a specimen requires only 60 seconds. While discussing the object chamber, mention should be made of the fact that delicate controls are provided to give transverse motion of the object in two directions, thus permitting the observer to view any portion of the specimen he desires.

During operation it is, of course, necessary to change photographic plates. Therefore, an airlock is also provided for the photographic chamber. The photographic plates used with the microscope are long enough so that a number of exposures may be made on the same plate, and an adjustable mask allows the width of the picture to be controlled at will.

The complete microscope stands about seven feet high and occupies not more than five square feet of floor space, and it is completely shielded from electrical and magnetic disturbances. Thus it can be fitted into any research laboratory, and does not require a special shielded room to house it, as did the earlier instruments.

The specimens for the electron microscope must be mounted quite differently from those for an ordinary microscope, since the electrons will not penetrate an ordinary glass slide. The most frequent procedure used for mounting objects

for examination is to suspend them in pure water or other suitable liquid, then to place a drop of the suspension on an extremely thin cellulose film which is supported on a fine mesh screen. The supporting film, which is of the order of 100 Å thick, is made by spreading a droplet of a solution of the celluloid on water. Other procedures are to suspend the object particles on the cellulose itself, or, where the object is self-supporting, to mount the specimen directly on the wire mesh.

The performance can best be described by showing micrographs that have been made with the instrument. In the fields of biology and bacteriology, the new microscope is a tool of immense importance.

As great as is the importance of this instrument in biology and bacteriology, its value to research and industrial chemistry is fully as great. For instance, details of surface conditions far below the resolving power of a light microscope have a considerable effect on absorption and other chemical properties.

The applications of the microscope even extend into the realm of metallurgy, although this is an entirely new field and the technique is not yet fully developed.

This only touches on the wide range of applications open to this new instrument which is capable of resolving detail as fine as 30 Å, that is between 50 and 100 times smaller than can be seen with the best optical instrument.

ACTION OF LIGHT ON ORGANISMS

By Kenneth V. Thimann
Harvard University, Cambridge, Massachusetts

As shown in the first paper of the symposium,[1] we are dependent on the sun not only for sunlight, but for most of our energy, including coal and petroleum. In the present paper I propose to discuss certain of the more important aspects of the influence of sunlight on the living organisms which inhabit our world.

The most obvious thing about light is that we see it. As stated in the first lecture, in the whole gamut of wave-lengths only a narrow band produces the sense of vision and is defined as light. What does seeing amount to? The essential parts of the eye with which we see comprise a lens and a receiving screen, the retina, which is placed in such a manner as to receive the bulk of the light at a focus, while the rest is spread out more diffusely over the remainder of the retina.The retina is connected to the brain directly by the optic nerve. The essence of seeing depends upon the fact that light falls on a substance in the retina called visual purple, which is very unstable and turns to a pale yellow compound under the action of light. It is the chemical change of this substance that finally results in seeing. Here (Fig. 1) is the retina of a frog which has been caused to look for a time at a barred window, then taken out quickly and fixed. You can see the stripes of pale yellow where the image of the light parts of the window has converted the purple pigment to yellow. Experiments on the chemical nature of visual purple show that it is related to carotene, the orange-red pigment of carrots. There is a large group of substances, the carotenoids, related to this pigment of carrots. Vitamin A is one of these, and indeed one of the reasons why this vitamin is so essential is that it is needed for the production of visual purple.

Man is a relatively complex organism. Small, simpler organisms can see in a simpler way; they respond to light by moving towards it. The unicellular flagellate, Euglena, moves forward by lashing the water with its long flagellum. When a beam of light falls on Euglena, it moves toward the source of light, provided the beam falls on a certain small red spot. If a micro-beam is used, it can be directed to other spots

[1] Presented before the symposium on Solar Energy, Harvard Chapter, 1940. Two other papers have been published in the Quarterly: I. D. H. Menzel (Vol. *28*, 157-164); III. H. C. Hottel (this issue, pp. 49-60).

and the Euglena will not move. This is, then, a photo-sensitive spot—an eye-spot or stigma. In some algae the stigma is more elaborate and, in some cases, even looks like a lens. It is hardly probable that the lens can be functional, however, since the lens is, as often as not, on the inside instead of on the outside of the spot. However, the stigma might be called an isolated retina. Now it is of considerable interest that the pigment which responds to light here has been found also to be a carotenoid.

Fig. 1. Retina, frog, showing image of barred window. After Garten.

Thus these unicellular organisms, which may fairly be numbered among the reasonably low creatures in the evolutionary scale, probably use the same type of substance for responding to light as do we, at the top of the scale.

But Euglena, being unicellular, is by no means typical of the plant kingdom. Higher plants respond to light in a somewhat different way. Perhaps this is best understood by considering one's own personal reactions. Suppose that you are confined to bed, in such a way that you are more or less fixed at one end, and someone comes to see you. Being fixed at one end considerably limits your actions, but you express yourself as best you can by curving in various ways. Plants curve in response to light. Shoots generally curve towards the light. A plant which has been illuminated entirely from one side grows horizontally towards the source of light. In mustard seedlings, when fixed in the middle, the shoots grow towards the light and the roots weakly away from it. In many plants this movement of roots away from the light is not shown. Even the non-green plants, the colorless fungi, show curvature towards the light, although this is not true of all fungi. A common inhabitant of animal

dung is Pilobolus, one of the Black Molds, with stalks only 2 or 3 mm. in length. This plant, when ripe, shoots off its sporangia from the exact top of the stalk. Now it so happens that the stalk curves towards the light, and if an experiment is set up in which a narrow beam of light passes through a glass plate and then illuminates Pilobolus while the sporangia develop, then the stalks point toward the light and all shoot their sporangia toward the light, hitting the glass plate (Fig. 2). The

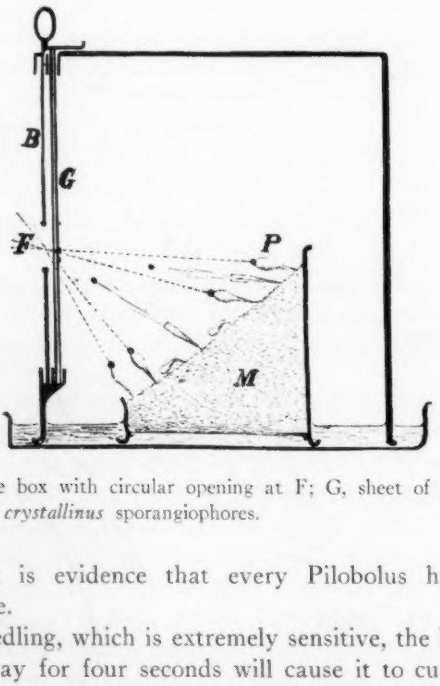


FIG. 2. B, opaque box with circular opening at F; G, sheet of glass; M, vessel of dung; P, *Pilobolus crystallinus* sporangiophores.

neat black dot is evidence that every Pilobolus has very nearly hit the bull's eye.

In the oat seedling, which is extremely sensitive, the light of a match held a yard away for four seconds will cause it to curve towards the light. In the seedling the conditions are not comparable with those in the fungi or algae, but the growth is controlled by means of a hormone. The growth hormone is secreted by the extreme tip and, as it travels down the plant, causes the lower part to extend and so causes growth. This can be very simply demonstrated—indeed, was so demonstrated 20 years ago—by the simple process of cutting off the tip of the seedling and replacing it on one side. The secreted hormone now travels down into one side, while the other side is without it. The "hormone side" grows more than the other, and so the plant curves. This experiment was the first good evidence that plant growth is controlled by a hormone. But there is more to this. When light falls from one side, more of the hormone travels to the shaded side than to the lighted side,

that is, instead of being distributed equally the hormone is distributed unequally. Hence the shaded side grows more than the lighted side and, consequently, the plant curves towards the light. This has been shown by allowing the hormone from the two sides to diffuse out into two small blocks of agar. The amount of hormone in the agar is then determined by putting it on one side of a standard plant completely in the dark. The agar from the bright side (B) causes a smaller degree of curvature than that from the dark side (D, Fig. 3).

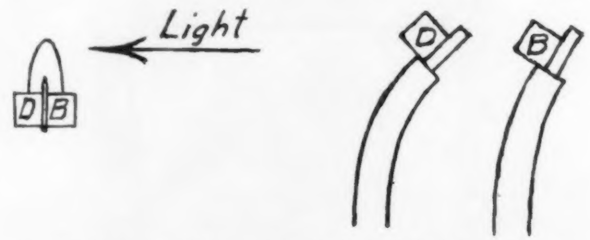


FIG. 3. Coleoptile tip arranged so that auxin from shaded side diffuses into one agar block, D, that from the bright side into the other, B. At right the blocks are assayed separately on test plants.

How is it that light falling on one side can produce an asymmetrical distribution of the hormone? This is a difficult question to answer. All such questions as to exactly how light can bring about biological reactions are hard. It is probable that there is a carotenoid concerned in this process also. We know that if one takes an intact plant and illumines different zones, illumination of the tip is the most effective to produce curvature. In other words, the tip is the most sensitive zone. Studies have shown that it is in the tip that a carotenoid is present. For this and other reasons it is probable that the carotenoid, which absorbs light, influences the transport of the hormone. It can be seen how analogous this is to the process of vision in animals.

These are responses of certain creatures to light. They show how organisms can detect light in one way or another. But the most important function of light, from our point of view, as creatures with appetites to be satisfied, is of quite another type. It is the conversion of carbon dioxide in the air into organic matter, the process of photosynthesis. Without green plants, life on the world would be impossible. As is generally known, the process is performed by the green pigment, chlorophyll, distributed in small bodies known as chloroplasts. Chlorophyll is specifically a plant pigment and is not found in animals. There is one possible exception to this fact, namely the curious leaf insects of Asia which are shaped like leaves, and also resemble leaves in their

general coloring. Because they are so much like leaves, it has been said that they have even tried to feed upon one another, by mistake. They also show autumn coloring. The reason I have mentioned the leaf insects is that the green pigment in these insects is supposed to be chlorophyll or some related substance. It would be interesting to investigate this matter, but even if it turns out to be chlorophyll, it will not necessarily mean that the animal can photosynthesize.

An interesting fact about chlorophyll in leaves is that it is always accompanied by yellow and orange pigments belonging to the carotenoids. In autumn, when the chlorophyll bleaches out, the yellow pigments are very obvious. If the leaf pigments are extracted and separated by absorption on chalk or magnesium oxide, the different layers may be separated. Here, again, is the remarkable fact that where light absorption has a biological effect these carotenoids are present. There is as yet no known exception to this rule. Just what their function is in photosynthesis is not known. We know that, of the rays which are absorbed by the green leaf, only those rays absorbed by chlorophyll are effective in photosynthesis. When light passes through a solution of chlorophyll dark bands are seen indicating where it has been absorbed. There is very little absorption in the green.

Chlorophyll exists in two forms, *a* and *b*, both being present in leaves. The absorption spectrum of *b* is very similar to that of *a*. There is an important absorption band at 650 mμ, that is, in the orange-red, and again an absorption band in the blue-violet. This absorption spectrum agrees reasonably well with the absorption spectrum of the whole leaf. On the other hand, the carotenoids, being of different color, absorb in different zones. Chlorophylls absorb mainly red and blue and reflect the green; hence they look green. On the other hand we have seen that the carotenoids look red, that is, they absorb mainly in the blue and violet and reflect the red. Now photosynthesis occurs best in the red and orange-red, in a band close to 650 mμ with a secondary important peak in the blue. The green waves are least effective. The wave-lengths effective in photosynthesis, therefore, correspond to those absorbed by chlorophyll. This means that light absorption by carotenoids apparently has no direct function in the light-absorbing process of photosynthesis. Their exact action is not known. It is probable that they are connected somehow with the photosynthetic processes, however, since, as emphasized above, they always occur where biological reactions to light take place.

Since it is necessary for plants to absorb light, one would expect to find that they are very well adapted for this. Most of them possess broad flat structures, rich in chlorophyll,— the leaves, and these are placed

nearly at right angles to the direction of the light. One sees this clearly in trees. This maple shoot (Fig. 4) shows how individual leaves are at right angles to the incident light. In some cases, as in the geranium (Fig. 5), the leaf-stalks curve so that the leaves become perpendicular

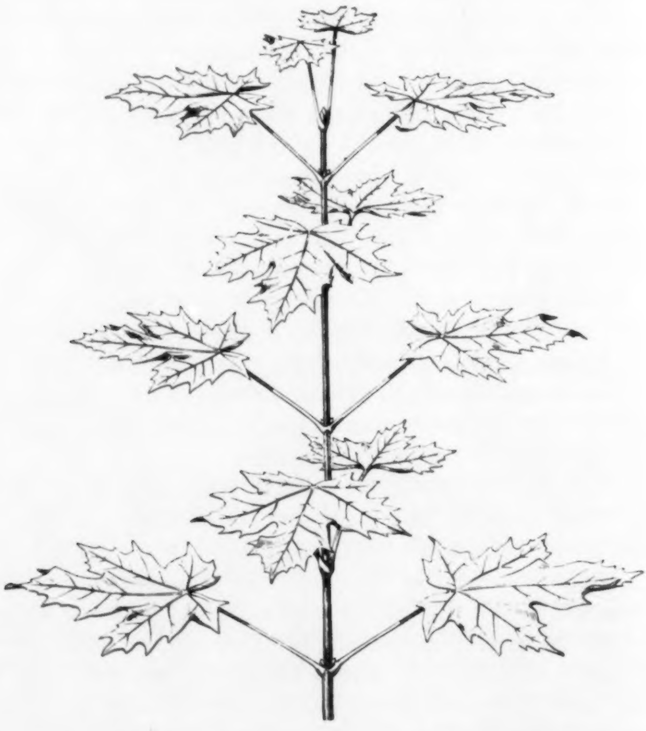


FIG. 4. Shoot of Norway Maple, showing the horizontal display of leaves. After Kerner.

to the light. Some plants do this so quickly that the leaves actually follow the sun around the sky. Such movements of leaves are really a special case of curvature towards light. What is involved is not exactly a curvature *towards* light, but a curvature controlled by light, through the hormone distribution in the leaf-stalk. But the result is that the leaf-blade comes out perpendicular to the light.

An extreme and beautiful case is the so-called compass plant. The impression one gets is that all the leaves point north and south. The plant is, actually, fairly accurate in its pointing north and south. The reason is that during the time the compass plant is growing in northern

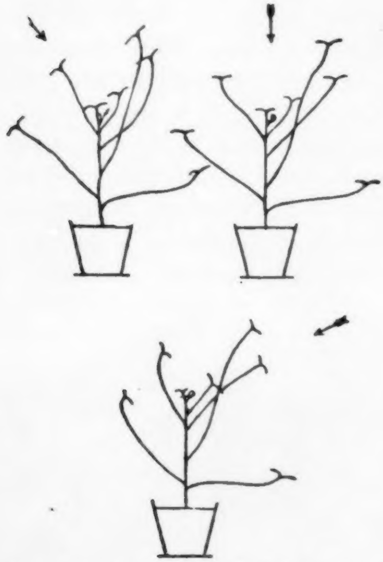


FIG. 5. Geranium plant adjusting its leaves to be perpendicular to the direction (arrows) of incident light. After Lubimenko.

latitudes, where it is found, actually more light falls from the east and west, than from the north and south, direction. Therefore, if the plant

FIG. 6. Shoot of compass plant, *Lactuca scariola,* showing the arrangement of leaves in one plane (north and south). After H. Dolk.

is to adapt itself so as to receive the total maximum during its growing period, the leaves must be correspondingly oriented. This involves complicated reactions; there are three separate and independent curvatures at the base of the leaf. In Figure 6, it can be seen that leaf B, which is inserted on the east side, merely bends towards the stem, while leaf A, on the north side, is twisted into the plane of the stem.

The ability of plants to curve towards the light and bring leaves perpendicular to light has the important result that the plant can make the most of its leaf surface. The shadowed leaf will move sidewise, from

FIG. 7. Ivy plant viewed from the direction of the sunlight, showing the "leaf mosaic." After Lubimenko.

underneath the leaf that shades it, out into the sunlight. Ivy is a well-known example (Fig. 7); it adjusts its leaves so that they are exposed in the best way possible to sunlight. Whenever a gap occurs it is filled by a leaf underneath. Thus the plant provides the maximum of absorption surface and, therefore, takes up practically the whole incident light. And this again means, speaking in larger terms, that a very large fraction of the land surface will be covered with green leaves.

This is not to say that a large fraction of the light is used up in photosynthesis. Unfortunately, this is by no means true. A large amount of energy that falls upon plants is either reflected or converted into heat. The actual amount going into the plant structure can be calculated from the amount of organic matter built up. The main products of photosynthesis are starch and cellulose. They consist of sugar molecules linked together. It can readily be calculated how much sugar (glucose) is equivalent to a given amount of starch and cellulose. Here is an attempt by Transeau to find actually how much light has been used in photosynthesis:

Energy Balance Sheet

Total dry weight of an acre of corn (10,000 plants)	6000 kg.	
Less ash (inorganic matter)	300 kg.	
Total organic matter		5700 kg.
Equivalent of this in glucose		6700 kg.
Plus organic matter lost by respiration during the season (expressed as glucose)		2000 kg.
TOTAL sugar formed (expressed as glucose)		8700 kg.
Energy needed to synthesize 1 kg. glucose (from heat of combustion)	3800 KCal	
Energy needed to synthesize 8700 kg.		33,000,000 KCal
Total solar energy available (1 acre)		2,040,000,000 KCal

$$\text{PERCENT OF AVAILABLE ENERGY USED IN SYNTHESIS} = \frac{33 \text{ million}}{2040 \text{ million}} \times 100 = 1.6\%.$$

Taking the weight of an acre of corn and making various corrections for amount of ash, the change from glucose to starch and cellulose, and loss by respiration, a figure is obtained for the total organic matter formed, expressed as glucose; then from the energy of the glucose as liberated in burning, and the amount of solar energy received, it is found that only 1.6 per cent is actually used in photosynthesis. Considering that the area of the land is more or less covered by the green plants, the actual consumption of light in photosynthesis is not very great.

There are also certain photosynthetic bacteria, whose products are not carbohydrates, but more complex fatty acids. These have a photosynthetic process that differs from that of green plants. They must have no oxygen, and they do not evolve oxygen, whereas the green plants do. They set free sulphur and certain organic compounds. Still, we have reason to believe that in these very different organisms, the process is essentially the same. One reason is that these purple bacteria contain both a special form of chlorophyll, and also a large amount of a substance related to carotene. Here again, what looks like a different type of process is apparently controlled by the same chemical mechanism.

It is probably not necessary to tell you that the study and analysis of photosynthesis have proven unexpectedly difficult. Photosynthesis goes on only in the intact cell. Many kinds of mashes, brews, etc., will respire, ferment, and perform other biological functions, but such preparations of green plants will not photosynthesize. This means that, in order to study photosynthesis, one has to take the intact material and observe it from the outside. It is not possible to go in and break up the reaction into its constituent parts. It is much like what happens about Christmas

time when we try to find out what is inside of the package without actually opening it. We can feel it and shake it to get some idea, but it cannot be opened until the 25th to see what is actually there. To do the same thing with photosynthesis has occupied a great many people a great many years, and the net result has not been very much. A few clarifying ideas have come out of it.

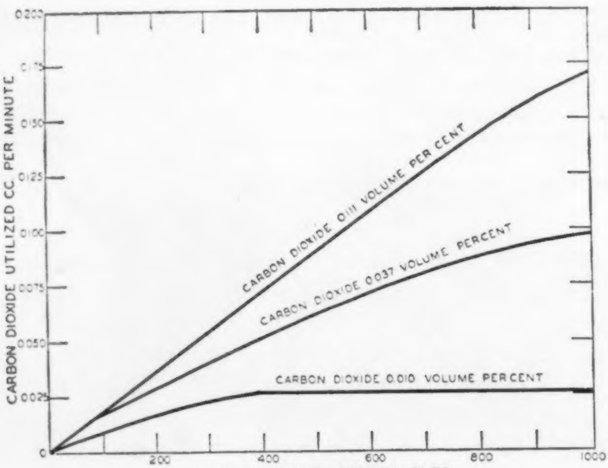


FIG. 8. Relation between different light intensities and rate of photosynthesis of wheat plants at three different carbon dioxide concentrations. Data of Hoover, *et al.* (1933). From Meyer and Anderson.

Probably the most important is the understanding of the way in which photosynthesis is controlled by external factors, particularly the amount of light and the amount of carbon dioxide supplied. This has been studied by measuring the *rate* of photosynthesis, a measurement which can be done easily enough, by following the evolution of oxygen or the consumption of carbon dioxide. In Harder's experiments, as in those of later workers, the rate of photosynthesis was measured as a function of the intensity of light. The lowest curve of Figure 8 shows that as light is increased the rate goes up and soon reaches a maximum. When it reaches this maximum, it is clear that more light is of no value. What is of value, however, is to give a larger amount of carbon dioxide. In the next curve the carbon dioxide concentration was nearly four times as high. The curve rises more steeply and continues sloping very much longer, that is, the rate is a function of light intensity over a greater range. A further rise in carbon dioxide causes a still greater effect. Evidently, then, when the light is very strong, light is not the

principal factor limiting or controlling the reaction, but carbon dioxide is. This whole procedure can be inverted by holding the light constant and changing the amount of carbon dioxide. If the photosynthetic rate is plotted against carbon dioxide concentration we again obtain a curve rising to a maximum and then remaining parallel to the axis. When this point is reached it is useless to give more carbon dioxide, but the rate will be increased by increasing the light intensity. These relations have been established with algae, mosses and higher plants, so it is evident that they are quite general. The point is, that if we choose the conditions, we can make either carbon dioxide or light the limiting factor.

When light is the limiting factor the situation can be compared directly to a number of known photochemical processes. Photochemical reactions are not affected by temperature. Thus in photosynthesis, when conditions are such (high carbon dioxide concentration) that light is the controlling factor, we should expect warming or cooling of the plant to have no effect on the rate, and this is found to be exactly the case. The reverse is true in non-photochemical process, that is, warming or cooling are effective in changing the rate when carbon dioxide is the limiting factor. From this it follows that by suitable selecting of conditions the process can be controlled either by a light reaction or by a chemical reaction which varies with temperature, or, if you prefer, a light reaction and a dark reaction. This, it may be said, is the principal result of the experiments on photosynthesis. By the application of this simple principle of limiting factors the conclusion is reached that there are at least two processes in photosynthesis: maybe more, but there are at least two. This has also been inferred from experiments on the poisoning of photosynthesis, some poisons acting on the light reaction, some on the dark. Now it is very unfortunate, having got to this point, that we cannot sit down and formulate just what they are. We know they are there, but we don't know what they are.

When it comes to growing plants in the field or forest, this principle comes into play as a very important one. If a plant is inadequately supplied with nutrients, then the best that can be got out depends on the nutrient in the smallest amount. And so growth can be limited by a wide variety of limiting factors. In connection with the work of the Maria Moors Cabot Fund, studies are being made by Professor Gast at the Harvard Forest on the amount of synthesis carried out by seedlings of forest trees under conditions in which different nutrients are the controlling factors. In the case of nitrogen there is obtained a curve almost exactly the same as in Harder's and in other experiments. That is, if the yield of the plant is plotted against the amount of light, the yield goes up to a maximum as the light increases. This is done where

very little nitrogen is available. But if the same experiment is carried out when much more nitrogen is taken up, we get very nearly a straight line, so that, under high amounts of nitrogen, we get a tremendous response to light. Precisely the same thing can be done by giving fixed amounts of light and varying the nitrogen. It amounts to the fact that when the nitrogen supply is low, increasing the light is of little use because nitrogen soon becomes a limiting factor.

Now the Cabot Fund is intended to look toward more efficient use of photosynthesis. There is evidence that the world's supplies of oil will only last a few hundred years, whether it is one hundred or several hundred. After that, unless the experiments Dr. Hottel is going to discuss are remarkably successful, we shall have to look to timber or something prepared from wood or plants. Three or four hundred years may seem long to us, but it is not long in terms of tree generations. Hence if we are to develop more efficient use of sunlight by trees, there are not many generations to use. We can do a number of simple experiments, but if we are going to grow trees for 50 years apiece we cannot do it many times. At the moment we do not do any such thing as giving artificial fertilizer to a whole forest. Nevertheless, the considerations above indicate that in the long run, for the maximum possible yield, it may be necessary to do things like that.

Also there is considerable variation among trees of a given species, some using light more efficiently than others. There is also a variation between species. Different kinds of trees utilize light with different degrees of efficiency. Within a group there are very wide variations and one aspect of the work planned is to select from large numbers of trees the fastest growing races and to develop them, so that forests can be replaced with plants of relatively high efficiency. This work involves two kinds of procedures: one is breeding, the other is propagating. In order to breed and make hybrids, one must know something about pollen and, particularly, about the chromosomes of pollens. It so happens that in most of the important timber trees, which will probably prove our principal means of accumulating energy, these facts are not well known. Professor Sax is making a study of the successful production of hybrids, and choosing trees which for one reason or another seem likely to become important.

The second procedure for developing such plants is that of vegetative propagation. One must be able to multiply the hybrids which are found to be efficient. This is usually done by rooting cuttings, but unfortunately this is also difficult in the majority of our forest trees. The advantage of this method is very great in that one does not need to wait 10 or 20 years for the plant to produce fruit. So, under the Cabot Fund, one project has been to study the propagation of some of the

more important forest trees. Here the recent knowledge of the plant hormones which control root formation has come in very useful. Optimum hormone conditions can now be provided. Many important trees, such as hemlock, white pine, and oak, have been successfully rooted and grown from cuttings in our experiments. It so happens that the rooting of such "difficult to root" plants is not entirely controlled by the root-forming hormone. We know that these plants grow vigorously and that the same hormone is necessary for growth as for rooting and still, in general, they do not root. This means that we have to study not only the known hormones, but also the unknown and, particularly, it is necessary to study the internal factors influencing the growth and rooting of plant parts. An example of the influence of unknown internal factors is given by red oaks; ordinary cuttings rarely root but, in our experiments, cuttings treated with hormone gave excellent rooting. The reason is that basal parts of the plants only were used. By the study of such things as the position of cuttings, age of cuttings, age of trees used for cuttings, relation of branches to one another and many other internal factors, it has been found possible to root cuttings of almost any plants by suitable regulation of conditions.

It is apparent, therefore, that the effect of light upon organisms covers a very wide area. Even the study of the process of photosynthesis has led us into practically every problem of plant physiology, from fertilization to nutrition, chromosomes, and hormones. One may conclude that to attack a field like this involves a wide access to different methods, and it is reasonable to suppose that only an attack of this kind is likely to be successful. The modern trend in research is that of collaboration between specialists in different fields and, in the future, important advances due to such collaboration are to be expected.

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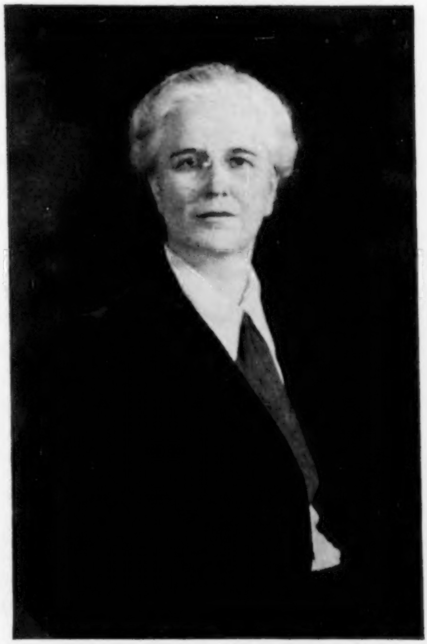

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By Arthur H. Compton
University of Chicago

In no other part of the world and at no previous time in history has life been so greatly influenced by science and technology as in the United States today. This influence extends not only to the means of living, but likewise to our amusements, our thinking, and to our religion. American civilization includes great cities, which need for their existence mechanical transportation, steel rails and girders, electric elevators, refrigeration systems to preserve food, careful sanitation, and control of disease. It embraces great areas of thinly populated farm land which supply the nation with an unparalleled abundance and variety of food. With the help of rapid communication, the government coordinates the activities of a widely distributed people, and our continent becomes a national community.

The uniqueness of American technological society was impressed upon me when recently I was speaking on the human effects of science to a group of students in India. I was about to remark upon the applications of science in everyday life, such as the electric light, motor transportation, mechanically woven cloth, scientifically selected seed, inoculation against disease, pasteurized milk, and conversations over the telephone, when I realized that these things were no part of the experience of my listeners. Even in England I found my colleagues dreading the approach of the world of technology which we have come to take as a part of life. East or west or north or south, the American sees a life less dependent upon technology than his own.

There is no doubt that science and its applications have supplied real needs. Through their help our average life span has been nearly doubled. We enjoy better food, housing and clothing. We are freed from long hours of physical drudgery. New opportunities for education, amusement, and cultural development abound. "Yesterday my son was married," remarked the foreman of our shop. "With a wife, a car and a radio, what more does a man want?" Thus the American rates high the contributions of science.

In our recreation we may try to lead a primitive life. Having motored hundreds of miles over hard highways, we arrive at a cabin in the wildwood, cook Chicago bacon on a stove using oil from Texas refined in New Jersey, and go fishing with an outboard motor made in Michigan.

Or it may be that we go so completely native as to canoe down the river, relying only on our Pittsburgh steel axe and matches made in Ohio from Louisiana sulphur to light our fires, fruit canned in California for our food, and mosquito netting woven in New England to keep off the pests. Though we want to be free from the ring of the telephone and to use the sun as our clock, we must take care that the milk we drink is pasteurized. Thus the American frees himself from technology!

Upon our social organization and our cultural life the effect of this technology has been revolutionary. The men and women who live in our cities and farms have become completely dependent upon each other. Each contributes his own share with the efficiency of a specialist, and receives from many others most of the things with which he lives. In prosperous days the resulting life in America is more abundant in material goods than has been the life of any large social group in history. Yet when times are hard, as in older less technical civilizations from time immemorial, unemployed laborers, dispossessed share-croppers, and bankrupt business men live on the verge of starvation, and curse the technology that has built a world in which their own efforts cannot bring forth the necessities of life.

In factory and in home are those whose monotonous tasks make them feel as cogs in a great machine. Yet the average level of public education by our schools and colleges is rapidly rising. Through magazines, radio, moving pictures, and unprecedented travel by rich and poor, our contacts with the world are greatly multiplied. New professions arise that are based upon science. It becomes profitable as well as satisfying to search for new knowledge, and scientific research becomes our great intellectual quest.

Science thus gives to man three Promethean gifts. First, it supplies more adequate means of living; giving longer, healthier life, and a richer variety of experience. Second, by placing a high premium on expert knowledge and by rewarding more abundantly cooperative effort, it stimulates man's social development. Third, science serves as a vehicle for cultural expression and forces further moral and religious growth.

The gift of fire was a mixed blessing to man. So also are the gifts of modern science. With new powers war becomes more fearful. Rapid social changes bring maladjustment and misery. Even the anchor of religion is found to drag as the storm of science blows. One is reminded of the legend in which the people complain to Daedalus that the steel sword he has given to King Minas will bring not happiness but strife. Daedalus replies, "I do not care to make man happy, but to make him great." For those who have courage, the new powers thus given by science pre-

sent a challenge to shape the life of man on a more heroic scale. Here is a vision of a new world which only the brave may enter.

Science Stimulates Social Growth

George Sarton, in his recent book, "Science and the New Humanism," shows how through the ages man's increasing knowledge of the world has made him develop a distinctive life. Science and its application, he points out, have made man human.

Note how technology in American society places an unprecedented emphasis upon the value of increased education. The use of steam and electric power has decreased the need for common labor, while growing specialization has increased the need for those who coordinate our activities. Thus the slave has been freed, and unskilled labor is to a large extent unemployed. Skilled labor, however, remains vital to American society for building and operating our machines, and is rewarded with shortened hours and higher pay. Business requires middlemen to handle its varied commerce. Vastly increased numbers of professional men and women have been absorbed in occupations of responsibility which before the era of technology were hardly known. Here we find the engineer, the secretary, the economist, the patent lawyer, the research scientist, and many others. The citizens responsible for planning the work of society have never been so driven by ceaseless demands as in today's America. Reflections of this pressure are to be seen in the multiplication of governmental offices, in the rise of schools of business and public administration, and in the frequency of nervous breakdown among professional men driven beyond endurance. The masters of society have indeed become the servants of all, in an unresting labor that knows no freedom. By emphasizing the need for intelligent direction, and reducing the need for unskilled labor, technology is thus spurring Americans of all levels toward an ever higher standard of training and education.

Our European contemporaries have presented cogent arguments to show that the American system of universally available higher education must lead to severe unrest as men and women trained for a life of the intellect find that they must live by their hands. In large areas of our country twenty-five per cent of the total population of college age are now attending college. Two generations ago the figure was two per cent. It is amazing that these vastly increased numbers are finding the white-collar jobs they seek. In spite of our mass education, unemployment is less frequent in the professions than in common labor. The prophets of doom had not counted on the growth of the specialized society based on technology, which has demanded increasing

numbers of highly trained men and women as rapidly as our universities have been able to supply them. The result instead of being tragic has been the happy one of giving our citizens an unparalleled opportunity for intellectual growth. Through their more extended education, millions of our citizens are awakening to a new understanding of life's values. Such is the humanizing action of science.

To visualize how our gradually growing knowledge has from the beginning stimulated man's growth, let us imagine the last million years of his history to be compressed into the lifetime of a middle aged man of fifty. Let us suppose that he is reading this article on a Saturday evening. It was then as a child that he learned the use of certain odd-shaped sticks and stones as tools. The meaning of sounds became definite as he learned to talk, and as his vocabulary increased so likewise did the clarity of his thought. By the time he was forty, he had developed the art of skilfully shaping stones to fit his needs. Last year he became an artist, and a few months ago learned to use simplified pictures as symbolic writing. Less than two months ago the Phoenecians introduced to him the alphabet, and after a fortnight came the brilliant art and science of ancient Greece. Five weeks ago was the dawn of Christianity and the start of the Roman empire, and he recalls how a week later Rome fell, hiding for some weeks the values of civilized life. Last Sunday morning, so the report has it, Galileo dropped the heavy and the light cannon balls from the Leaning Tower of Pisa, refuting a proposition of Aristotle and starting the period of modern science. By Wednesday afternoon this had led to building the first practical steam engine, and it was at about this time that the United States came into being. On Thursday the major laws of electromagnetism were being discovered which by last evening had given us the telegraph, the telephone and incandescent electric light. Only last night x-rays were discovered, followed quickly by radium and wireless telegraphy. It was this morning that automobiles came into general use. Air mail began to be carried only at noon today. Popular short wave broadcasts, practical color photography, and fluorescent lighting were unknown until this afternoon.

We were discussing recently the problems faced by the rising generation. My dinner partner remarked that she saw no need for worry on their behalf. With the introduction of the automobile, the moving picture and the radio it has been during our generation that the great changes have occurred. The rising generation can now use our experience as a reliable guide. This is comparable with the view of those economists who, noting that no further geographic frontiers exist, are basing their

predictions on the hypothesis that our nation has reached a stable economic maturity.

A survey of present technical publications and patent office records shows on the contrary that the rate of growth of our scientific knowledge and of useful inventions is at an all time high. It is these advances that are responsible for the accelerated social changes exhibited by our quick review of history. If our experience can reliably tell the rising generation anything, it is that they may anticipate an even greater development of technology and corresponding change of social customs.

The knowledge of nature, which from the beginning had been man's gradually but accidentally increasing heritage, has now become the conscious objective of alert minds. In the time of Benjamin Franklin, science was the hobby of a few amateurs. Now there are in the United States nearly two thousand research laboratories, equipped with refined apparatus, where men of the highest training are striving to enlarge our understanding of the world. It is their new-found knowledge which changes our lives.

The Trends of Social Evolution

We may think of these changes in man's mode of living as an aspect of adaptation to environment. It is in fact social evolution. In a short thousand generations, man has changed from an individualistic to a social animal, and that change is continuing at an increasing rate. It is thus important to consider what the directions may be along which this evolution will proceed.

It is clear that we may expect those modifications in our way of life to survive which give strength to the social group. Prominent among these strengthening factors are knowledge and cooperation. Enough has been said regarding the strength that comes through science and technology. The continuous growth of scientific knowledge which Sarton observes throughout human history is thus to be expected from the fundamental principles of evolution. In a highly competitive, war-like world, that society cannot long survive which neglects the truths of science.

Advances in technology enhance the value of specialization and cooperation. Without cooperation, knowledge cannot be made effective. If men divide into antagonistic groups, it becomes terribly destructive. Experience as well as theory has shown the superior strength of those social groups which work together. Thus a more closely coordinated and cooperative society is likewise to be considered an inevitable evolutionary trend.

It is noteworthy also that the conditions have now become such that the larger economic, social and political units are the stronger. Before the period of rapid communication and transportation large units became unstable. As a result of geographic exploration, steam and motor transportation, telegraph and telephone, press, the moving pictures and the radio, we already share each other's lives and obtain our needed supplies from far corners of the globe. Intellectually science has already made man a citizen of the world. The present turmoil is at least in part ascribable to the need by a technological world for the development of larger economic and political units. We are rapidly moving toward the condition under which the only stable life is that in which the whole planet is a unified community. With continued growth of science and technology some kind of world government now seems inevitable, and in the not distant future.

Does Science Threaten Human Values?

It is not surprising that those who have known and loved the tradition of classic culture should dread the approach of a technology which threatens the values they have cherished. They see science replacing the human interests present in literature, art and music with technological developments in which the human factor becomes less and less significant. The most fundamental values of mortality and religion are ruthlessly shaken, with the implication that their value is negligible. It is just because so many scientific men seem blind to these human difficulties that one feels the greater concern lest in following science mankind may lose its soul.

There is a passage in Plato's *Phaedo* in which Socrates describes his early interest in physics and how he had found that physics fails to account for the important things in life. Thus, he explains, Anaxagoras would say that Socrates sits on his cot waiting to drink the hemlock because of certain tensions of tendons acting on his bones. The true reason is rather because he has been condemned by the people of Athens, and as a man of honor he cannot creep stealthily away. Such moral forces as honor are not to be explained by science; yet these are forces that shape men's acts. Since it did not meet their human needs, the followers of Socrates and Plato abandoned science, and the study of the truths of nature were forgotten for a thousand years.

For those who know science, its inhumanness is a fiction. We have noted how science is making man develop into a social being. We can now begin to see the cultural expression of this social growth. We look to science to satisfy the human hunger for a better understanding of the world. The civilization which is being built with the tools of science is one

which requires man's moral growth. We must recognize with Plato that without a central objective life has lost its meaning. Yet in this age when men throughout the world are trying to formulate a philosophy by which they can live, it is to science that they are turning with confidence in its truth.

Cultural Life in a Changing World

"Johnny, is that your 'cello?" Kenneth, who asked the question, was the first playmate our son had found on coming to the new city. "One of the 'celloists in our junior orchestra has graduated to senior high, and we need someone to take his place." Thus Johnny found that after all he wasn't going to miss playing with the school orchestra which he had so enjoyed at home.

Ten years ago we were noting with alarm the elimination of the professional musician by the radio. The musical public was, we were told, degenerating from players to listeners. Now we find millions of Americans for the first time aware of orchestral music. In the shops the demand for violins and flutes and cornets and drums has multiplied. Most of these instruments have gone to the tens of thousands of school orchestras and bands which are giving boys and girls the chance to share in producing harmony. Throughout the country the musical standard is rising. College glee clubs sing better songs. Sound movies and radio programs find they must continually improve their variety. A hundred professional symphony orchestras now play where there were a score.

The example of the school orchestras is typical of the way in which a broader base for the fine arts is being developed among millions in our country. It is not impossible that use of the radio may mask the birth of a new era in American music. In a similar way good color reproductions of the best (and perhaps the worst) paintings have recently become widely available. One might have feared that the opportunity thus afforded for the vicarious enjoyment of great pictures would discourage the amateur painter who sees that he cannot compete with the masters. The director of the Metropolitan Museum of Art tells me, however, that sixty thousand professional artists are now listed in New York City, and that the interest in amateur painting is rapidly increasing. Over the country are to be found, likewise, camera clubs and photographic exhibits where amateurs vie with each other in finding the most pleasing effects. Thus artistic America as well as musical America is finding its soul in individual expression.

The culture of our scientific era is, it is true, that of a rapidly changing society whose customs and ideas are only partly adapted to the new conditions. For example, I have been living recently in an apartment by which a streetcar clangs its noisy course. The installation of these cars

gave the rapid transportation that made the city possible. Now, however, the demand is insistent that the streetcars be replaced by quieter, stream-lined buses that will permit conversation by day and sleep by night. Thus the first application of technology was to meet the primary need of transportation, but eventually the refinements come that add to life's enjoyment. As long as growing science brings such rapid changes in our life it is futile to hope to attain an adjustment of the art of living that can compare in refinement with the classic culture initiated by the Greeks and developed in Europe and England through centuries of slow social change. As our knowledge grows, however, we seek to build a greater culture upon a broader, firmer base.

Science in American Thought

It is but natural that in a society so profoundly affected by science our intellectual life should likewise be focused in that direction. At Oxford it remains doubtful whether science has yet earned a true place in education. At Chicago, on the other hand, three of the four main divisions of the University are called sciences. A part of this emphasis is indeed ascribable to the need for at least a passing knowledge of science in every profession; but it nevertheless represents truly our educators' judgment of the value of science in enriching life.

To the man of science himself, it is primarily as a method of developing the human spirit that he values his work. In this regard science is to him a truly cultural pursuit. His study affords exercise of imagination and broadening of perspective. Whereas to Plotinus it appeared that, "It is through intuition rather than through reason that we may approach our highest aspirations," the scientist finds that in the discipline of unprejudiced search for truth lies the beginning of wisdom. Thus, in the words of Thomas Huxley:

> Science seems to me to teach in the highest and strongest manner the great truth which is embodied in the Christian conception of entire surrender to the will of God. Sit down before a fact as a little child, be prepared to give up every pre-conceived notion, follow humbly wherever and to whatever abysses nature leads, or you shall learn nothing.

To a certain degree this humanizing aspect of sceince is esoteric, since it can be fully appreciated only by those who have themselves submitted to the discipline required to share in the effort to widen the horizons of knowledge. Certain fields of science, notably astronomy, have, however, enabled amateurs to take part in their enterprise, and anyone can learn to practice a scientific approach to the everyday facts which shape his acts. It is hard to suggest any method more effective in bringing about a widely spread regard for impartial truth than by the growth of such

active participation in scientific endeavor. Herbert Hoover speaks for American science when he "would strengthen the national fibre by inculcating that veracity of thought which springs alone from the search for truth."

This direct encouragement toward reliance upon tested truth is but one of the moral implications of science. Perhaps more evident in historical perspective is its indirect consequence in the moral growth required by the socialization of man. Just as the automobile demands sobriety, or congested life makes necessary careful sanitation, so the mutual dependence of people in a technological civilization implies consideration of the rights of others. James Breasted has shown how the growth of community life along the Nile stimulated among the Egyptians the "dawn of conscience." Professor Cheney, in his retiring presidential address before the Amercian Historical Association lists prominently among his "laws" of history the trend toward a greater consideration of one's fellows as society grows more complex. In our American technological society, when each contributes his expert part our needs are fully met, while hardship comes to all if any fails his share. Thus science and industry are emphasizing as never before the need of the will towards cooperation. This is simply the Christian doctrine of the love of our neighbors as expressed in service.

Science Demands Religious Growth

Both directly and indirectly science affects also religious attitudes. The effect of the impact of modern science on Christian doctrine is an example of a long historical development of religion as influenced by man's growing understanding. Among the more thoughtful members of the American community there appears no longer any serious intellectual threat by science against an adequately formulated religion. Saint Paul described the religious man as one who "is alive to all true values." By enabling men to see more clearly what these values are and to work for them more effectively, science has, as Dean Inge recently remarked, become an ally of religion. If our young men dream dreams of a greater world they would build, and our old men see visions of a better society, it is largely because of the new powers that science has given. As never before we can share with our Creator the great task of making our planet a fit place for life.

On the other hand the world of science and technology is one in which an adequate religion is most urgently needed. We have noted above that the great demand of modern life is for adequate guidance in directing the mighty forces at our disposal. Such guidance implies knowledge of the road toward the best. Thus attention to the fundamental problem of ethics is the supreme demand of an age of science. Technology supplies

the motive power. Organized industry and government constitute the control and steering mechanism. But who will tell us where to go? In America it is only our religious leaders who have seriously attempted to answer this question.

Most significant of the factors that give strength to man is the vision of a goal which he recognizes as worthy of his supreme effort. On this basis Lenin rallies all the Russias to support a communistic world revolution. Hitler makes a sick Germany throb with vitality by the sacrificial call to every man to devote himself to the welfare of the state. Here are unifying religions in action. If there is a fatal weakness in American society it is in our lack of objective. With our divided counsels, an efficient social evolution will not let us survive in competition with nations or social groups that know where they want to go. Our formal religious organizations offer just such divided counsels. As one who has been actively concerned with efforts to bring amity and understanding among Catholics, Protestants, and Jews, I find it easy to become discouraged. These are those who know best that to glorify their God they must seek the welfare of all mankind. Yet among them are suspicions and jealousies, deeply based upon historical conflicts, which roughen the road of friendly cooperation. If the counsels of our spiritual leaders divide us, where is our hope? We must look to them for vision. "Art thou the Christ, or look we for another?" "To whom shall we go?"

Science presents to religion the greatest challenge of a millennium, that of presenting modern man with an objective adequate to his needs. We cannot be satisfied with the cold, godless nationalistic doctrines of Europe. Untold strength and comfort lie in the ancient teachings; but we find no life in much of the diluted, supine and self-interested dogma that is now being taught in the name of religion. Yet religion we must have. Never were men more eager to work for the best. Without the unifying religion that can show us that best, our lives are purposeless and our society cannot long endure.

Science itself is not that religion. Nevertheless, though the student of science may not feel qualified to choose for others that which gives life dignity and worth, he does supply the data from which that choice must be made. How can we correctly orient ourselves without learning the facts about the world and dispassionately considering their implications? Thus the Christian's great need is, as Paul says, "that your love may grow richer in knowledge and perfect insight, so that you may have a sense of what is vital." It is, I believe, in just this direction that science must ultimately make its greatest human contribution. Science must clarify the vision of the seers who would point out to us the goal of life.

(*Continued on page 75*)

ARTIFICIAL CONVERTERS OF SOLAR ENERGY[1]

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A STUDY of the literature on solar energy utilization has convinced me of the existence of an unalterable tradition among speakers and writers on the subject. One must always begin such a discussion by expressing the earth's reception of solar energy in units no one has thought before to use, the more startling the better. In keeping with this tradition, I shall mention a few old figures and add my own. The earth and its atmosphere intercept the equivalent in energy of 21 billion tons of coal per hour; six million tons per second; the equivalent in three minutes of the annual American energy consumption of about one billion tons; energy at a rate sufficient each year to melt a layer of ice 114 feet thick; on an acre at noon the equivalent of the discharge of a healthy stream from a garden hose spouting fuel oil instead of water.

Having made the conventional beginning, let me add what many of you know; that figures such as these are almost irrelevant to the problem of practical utilization of solar energy. They have attracted uncounted crank inventors who have approached the problem with little more mental equipment than a rosy optimism. Now, an informed pessimism is sometimes the healthiest mood in which to approach an engineering problem; and I want to use a little space in an endeavor to put you in that mood. Consider a solar power plant utilizing one acre of land, and operating on the principle of conversion of solar energy to heat in steam used to run an engine. There is incident at noon, normal to the sun's rays and outside the earth's atmosphere, 7400 horsepower of solar energy. On a clear day, of this quantity about 5000 horsepower arrives at the earth. Allowing for the efficiency of collection of the sunlight as heat in the working fluid to be used in the engine, the quantity drops to about 3300 horsepower. Utilizing the highest achieved efficiency of conversion of solar heat to useful power (results of Dr. Abbot's experiments), the horsepower output drops to 490. These calculations have so far all been on the assumption of normal incidence

[1] Presented before the symposium on Solar Energy, Harvard Chapter, Spring, 1940. Two other papers have been published in the QUARTERLY: I. D. H. Menzel (Vol. *28*, pp. 157-164); II. K. V. Thimann (this issue, pp. 23-35).

of the sun on the collector systems. To achieve this the collector must be mounted to turn with the sun and must be far enough from its neighbor not to shade the latter in morning or afternoon. Introducing a ground coverage factor of one-third to allow for this, the output is cut to 163 horsepower. But this figure applies only to the hours when the sun shines with full intensity. Converting to a 24-hour basis of operation on clear days in summer in Arizona, the output drops to 83; or in winter to 46 horsepower; or for the year to 68 horsepower. Passing on to the average year of New York weather, the output is down to 30 horsepower. Even if one stops at a reasonably attainable value of 50 horsepower in Arizona, that figure is $\frac{1}{150}$th of the original 7400 horsepower.

For rough orientation as to the meaning of these figures, suppose the possibility of a 50 horsepower steady output from an acre in Arizona be accepted. To evaluate this power, let it be assumed that electric power can be produced in a large modern steam plant at a cost of 0.6 cents per KWH, or $53.00 a kilowatt year, making the output of our one acre worth $1900 per year. In the absence of knowledge of labor costs, maintenance, etc., one can only guess the capital value of such an output. Capitalization at 15 per cent is almost certainly over-optimistic, and even that yields but $13,000 to spend on the entire plant, or about $2.60 per square yard. Since the ground coverage is but one-third, $8.00 are available to build each square yard of reflectors, mounts, and accessories. The result is one so often encountered in engineering projects: indecisive. It may be possible to build a plant for such an amount; much more exact knowledge of performance and costs is necessary than was at hand in making the above rough estimate. What I have particularly wanted to emphasize by this preliminary consideration is perfectly obvious to the engineer, namely, that solar power is not there just for the taking!

However, this preview has at least indicated that solar power is not completely outside the realm of economic feasibility. It is worthwhile, then, to examine in more detail the problem of use of solar energy by conversion to heat, a problem which has commanded the attention of engineers for three-quarters of a century.

First, a moment on some elementary principles of heat transmission. If a black metal plate is exposed to the sun, and cooling water is run under the plate fast enough to keep the plate from rising appreciably above the surrounding air temperature, substantially all the energy of the sun's rays intercepted by the plate shows up as energy in the water; the efficiency of collection of heat is nearly 100 per cent, but the value of the heat is low because of its low temperature level. If the water enters 50° F. above the surrounding air temperature and flows

through fast enough hardly to rise in temperature, there is the same interception and absorption of solar energy by the plate; but now much of it is used in keeping the plate up to temperature; it is lost to the surroundings by radiation and convection, and very little of the absorbed energy appears in the water stream. To improve the efficiency the losses must be cut down. There are several ways. The back side of the plate may be insulated, since it never sees the sun. Or a plate of glass may be placed over the metal plate and parallel to it, with an inch or so of air space between. Then the plate receives and absorbs almost as much sunlight as before—the glass transmits about 90 per cent —but the losses from the metal to the outer atmosphere are reduced: the convection loss because of the imposed stagnation of the air, and the radiation loss because glass, though transparent to the sun's rays, is opaque to the long-wave infra-red radiation emitted by the hot metal plate. Variations of this idea include the use of several glass plates and of glass vacuum chambers. Another method of cutting down losses is to reduce the area at which losses occur relative to the area of the interceptor of the energy to be collected. This may be done by choosing the most favorable orientation of the plate, that is, normal to the sun's rays, or by use of a concentrating device, such as a mirror, which intercepts rays covering a large area and brings them to a focus on an object of much smaller area where the heat loss is consequently correspondingly small despite the high temperature.

From this discussion there emerges a three-fold basis of classification of solar energy collectors: (1) by nature of orientation of the collector (whether and how completely it follows the sun), (2) by amount of concentration achieved by mirrors, (3) by amount and type of insulation of the receiver surface. It is perfectly obvious that many of the early inventors and engineers in this field were familiar with these principles in a general way. (A lantern slide was shown, presenting some of the efforts of the past so classified.)

One might now ask, "With all this work, have not the possibilities of energy production by conversion to heat been so thoroughly studied as to yield a definite answer?" Unfortunately, no. Qualitative familiarity with the principles involved these men had certainly; but with the exception of the work of Dr. Abbot, their experiments and records indicate inadequate quantitative knowledge of the problem. As an example, consider the simplest possible collector, the flat plate insulated with several air-spaced glass layers. Willsie's work at Needles in 1909 indicated the possibilities of this simplest of solar plants, but it left unanswered the question of merit relative to the much more efficient—and more expensive—plant of Abbot, and did not yield data permitting

the design of such a plant for any given climate. Among the projects at M. I. T. made possible by Dr. Godfrey Cabot's endowment for research on utilization of solar energy is one having as its first objective the determination of the performance characteristics of solar energy collectors of different types, the performance, of course, being correlated with records of incident solar energy so as to permit calculations of expected performance in any locality where sunlight records are available. The first and so far the only type of collector studied has been the flat plate, which will now be considered briefly.

Since each additional layer of glass and air cuts down the losses from such a plate, it is apparent that with glass having perfect transmission one could build a collector which, without any focusing or concentrating device, would still collect efficiently at a very high temperature level. But the best glass is not perfect. It doesn't absorb much solar energy when one picks the right glass—and there is ample evidence that early experimenters were too casual in their choice among glass in that respect—but there is a reflection loss of about 4 per cent at each surface. Consequently as glass plates are added the point is ultimately reached where the reduction in heat loss from the metal plate is more than offset by the reduction in intensity of incident radiation due to reflection losses. The optimum number of plates to use will be less the more intense the sunlight, more the colder the weather and the higher the temperature of collection of heat.

The controlling part played by reflection losses in the design of flat-plate collectors having been brought out, the desirability of a low reflecting glass was discussed with Professor Hardy, of our Physics Department. The result was the invention by Drs. Turner and Cartwright of a method of processing glass to give it a permanent surface of reflectivity approaching zero at one point in the spectrum. The process has already demonstrated its importance in a great many uses ranging from spectacle lenses through bomb sights to high speed cameras and the solar corona camera which was described to you in the first article of this series. Here is an excellent example of a need in one field stimulating research, the results of which have many applications in other fields. The special glass has not yet been used for an experimental solar energy collector, but calculations indicate that its use should make possible the attainment of temperatures up to 800° F. without any mirrors or lenses or so-called concentrating devices.

Another problem of flat-plate collectors is that of optimum tilt. Obviously they are too cheap a type of collector system to warrant being mounted to follow the sun, but they may profitably be tilted permanently towards the equator. A little consideration will indicate that

the optimum tilt depends very definitely on the use to which the collected heat is to be put. If the objective is the maximum collection during the entire year, tilting should favor the summer season. If, on the other hand, the objective is to supply heat for a load which varies throughout the year, the tilt should be chosen to favor that part of the year in which the load is highest.

As to the use of such collectors, it has already been indicated that one must find first just what they can do. But speculation is permissible. One might visualize a large artificial lake with sloped sides formed by throwing up an earthen ring around a surface-scraped center, the bottom and sloping sides being surfaced with asphalt. Floating on this lake, which is, say, 20 to 40 feet deep, is an enormous raft covering it completely. On the raft is a layer of insulation, then a system of flat-plate collectors. Forced circulation of lake water through the collectors whenever they attain a temperature above the reservoir will produce a large body of hot water available for continuous operation of a power plant. The working fluid in the engine might be low pressure steam or, to cut down engine size, a fluid which boils at lower temperatures. It is not possible to state at this time whether such an idea has possibilities.

Another less ambitious use of flat-plate collectors might be that of house heating in relatively cold, but sunny climates, or summer air conditioning. Some preliminary figures may indicate the prospects in this direction. Consider house heating in New England, and take as a basis the furnishing of one therm of heat throughout the heating season—100,000 B.t.u.: the heat obtained by burning one gallon of fuel oil with normal efficiency of combustion. If one square foot of flat-plate receiver covered with three plates of glass and tilted 40° southward is operated in connection with 1½ cubic feet of water in a well-insulated tank, and the water is pumped from the tank to the receiver and back whenever the receiver is hotter than the tank, the combination will supply all but 15 per cent of the 100,000 B.t.u. required during the season; the 15 per cent has to be supplied as auxiliary heat in December, January, and February. The value of the heat saved is the cost of 0.85 gallons of fuel oil, or about 6c. Capitalizing this at 6 per cent gives only $1.00 available to be spent on the roof collector and tank. This is plainly not enough, but the answer is interesting because we have not determined the optimum number of glass plates, or tilt, or ratio of roof to tank area, or considered the possibility of some day having treated glass of lower reflectivity. More particularly, the idea looks interesting for localities where the ratio of winter to summer sunshine is somewhat more favorable than in Boston, and the winter heating requirements somewhat lower. According to a recent publication of Dr. Abbott's, Dr. F. G.

Cottrell has proposed a somewhat similar storage system in which sand is to be used instead of water. Whether the advantages of low cost installation and ability to store heat at a higher temperature would be offset by the disadvantage of lower efficiency of collection is a point requiring study.

Whether the use of flat-plate collectors together with a storage system is economically possible for house heating or air conditioning in certain areas of the earth, whether other types of collector will prove cheaper for these uses or for power generation, whether power generation from solar heat demands the development of a new heat engine cycle, and whether power generation by any process dependent on direct conversion of sunlight into heat with consequent unavoidable losses due to the degradation of energy is sound—these are questions which it is hoped this program will help to answer. Regardless of the result, the present considerable and increasing importance of solar heat for hot water in certain parts of this country indicates the need for a comprehensive study of the factors involved in the design of collectors.

Now to come to a second project, related to the one just discussed. Conventional heat-power plants are characterized by a cost of power production depending enormously on the capacity of the plant; and we have seen that solar power does not now look very attractive when compared to large-scale operation of steam plants. If, on the other hand, it were possible to operate small solar plants with an efficiency comparable to large ones, the comparison with fuel-fired plants might lead to some very different conclusions. So far as the collectors of the sunlight are concerned there is little indication that the cost should be other than proportional to the amount of collector area. If then it were possible to devise an engine with moderate efficiency even in small units, one might have something worthwhile. The second project is, in effect, a study of a type of engine which may have just such desired characteristics. When two dissimilar conducting materials are joined to form a loop and the two junctions are kept at different temperatures, heat flows into the loop at the hot junction, a portion of its energy is converted to electrical energy and the rest flows out of the cold junction as heat. The phenomenon involved here has itself long been known; many investigators have been led to speculate upon it as a possibility for large-scale thermo-electric power production, but then to dismiss it as unimportant because the effect is small. The best results of the methods showed an over-all efficiency of conversion of energy from gas to electricity of only 0.6 per cent. Consequently, until recently, the sole use of the phenomenon has been in the measurement of temperature.

In trying to better these results, one naturally asks, first, the question "What property must a metal or alloy have besides high thermo-electric power if it is to be of interest for heat-power generation? Plainly, the material should have a low thermal conductivity to minimize the loss of heat flowing from the hot to the cold junction. Moreover, the electrical conductivity should be as high as possible in order not to dissipate an excessive amount of electrical energy as heat within the "engine." The ratio of the two quantities, thermal conductivity to electrical conductivity, is known as the Wiedemann-Franz ratio; and it has just been shown that this ratio should be as low as possible. A correlation of data from the literature and a consideration of theoretical limitations indicate a sort of conspiracy on the part of Nature to prevent the finding of any material with a Wiedemann-Franz ratio less than a certain minimum value indicated by the straight line on the diagram (a lantern slide was shown). A study of the properties of zinc-antimony alloys indicates that the thermo-electric power is a maximum for an alloy containing 36 per cent zinc, but that, due to the extremely abnormal value of the Wiedemann-Franz ratio in this alloy, there is an advantage in use of an alloy containing 43 percent zinc, since the thermo-electric power of such an alloy is almost as good as the best, and the Wiedemann-Franz ratio is very much more favorable.

An "engine" consisting of an alloy of zinc and antimony containing 43 per cent zinc against the alloy copel has been found to produce a 5 per cent useful conversion of heat to electrical power in the external circuit, when the temperature difference of the hot and cold junctions of the system is maintained at 400° C. To the layman this may not sound very imposing, but it is to be remembered that 25 percent efficiency is attained only in the best of modern steam power plants and that 5 per cent would not be considered bad for a small engine. Moreover, it is to be remembered that a great many alloys and compounds exist, the thermo-electric properties of which are unknown, that it is not inconceivable that further study of the problem may produce a material increase in efficiency in this kind of an engine. With such an idea in mind, there has been initiated at M. I. T. a program of study of the thermoelectric properties of various compounds and alloys. The work is in too early a stage to justify consideration at the present time.

So far in this discussion only the so-called heat engine has been considered as a means of conversion of solar energy to useful power. The term, to an engineer, means a device which receives energy as heat at a certain temperature, converts part of that energy to useful power and throws away the rest to a so-called heat sink at a second lower temperature. That this discussion was concerned in the first instance with the use

of steam in the engine and in the second instance with the use of a thermocouple for conversion to power is immaterial; in each case the first step has been the conversion of solar energy to heat. Now, there is available to the scientist and engineer a powerful tool, known as the second law of thermodynamics, that permits him to appraise the possibilities of the heat engine; and it tells him, for example, that the enormous reservoir of heat which the earth's atmosphere constitutes is not available for use in a heat engine. This same second law of thermodynamics states that, in the act of collecting sunlight and converting it to heat at a lower temperature level, a degradation of solar energy has occurred; the energy has been made less available for conversion to power even though none of it has been lost; and no process—no matter how clever the inventor—can restore the energy to a form as intrinsically useful as when it arrived here as solar energy just before its conversion to heat.

In consequence of this important limitation on what can be expected so long as one's interest is restricted to heat engines, it is appropriate to consider other means of conversion of solar energy to power which do not involve as a first step the collection of the energy as heat, but which instead make use of the special nature of the energy as it arrives. Solar energy reaching the earth consists of a jumbled mass of radiations of wave-lengths varying from the short ultra-violet through the visible spectrum and out into the infra-red, roughly one-third of the total energy lying in the visible spectrum. The radiation might be likened, if the analogy is not pushed too far, to a shower of bullets—unit quantities of energy, known as quanta, each of a particular wave-length. The quanta of shortest wave-lengths have the greatest unit energy content; and almost two-thirds of the total energy consists of relatively impotent quanta in the infra-red. If, instead of pouring all these quanta into the funnel of a heat engine, they are given a chance to show their individuality, what are their specialties? One, of particular interest to us at present, is the phenomenon of photo-electricity, the ability of light quanta of certain wave-lengths to knock electrons out of atoms or atomic lattices in crystals and produce an electric current.

Many of you have encountered this phenomenon in using that type of camera exposure meter which indicates on a dial the intensity of illumination. Light is there being converted into electrical energy which is in turn used to make the galvanometer needle move. The light-sensitive unit of such a device is one of two kinds, each referred to as a blocking-layer photo cell. The copper oxide cell is typical; it consists of a massive plate of copper which has been oxidized on one face and then etched, to produce thereby a layer grading from cuprous oxide through all proportions of oxygen down to pure copper. The cuprous

oxide surface is covered with a thin film of another metal, so thin as to be transparent to light quanta. There is thus produced a sandwich in which the outer layers are metal and the inside layers consist of material graded in character in a direction normal to the surface. If a quantum of visible light strikes the thin metal cover of the cuprous oxide, it passes through that and through the cuprous oxide layer, penetrating to some point in the structure where the composition lies between that of cuprous oxide and copper (the so-called blocking layer); and there the quantum—the bullet of energy—succeeds in knocking out an electron from the crystal lattice. The electron, being liberated in territory where the view depends on which way it looks, finds, in general, that the going is easier when it migrates towards the copper rather than through the cuprous oxide to the other metal film. This preferential movement of the electrons in one direction constitutes an electric current.

How important is this phenomenon for power generation from sunlight? Tests on copper oxide photocells indicate that of the visible light quanta falling on such a cell only about 5 per cent succeed in causing an electron to show up in the external electric circuit, that, furthermore, the voltage efficiency of the system is only about 10 per cent, with a consequent overall efficiency of conversion of luminous energy to power of one-half of 1 per cent. Preliminary calculations indicate that a tenfold increase in this efficiency would make copper oxide cells interesting for solar power production; and there is no present reason to believe such an accomplishment impossible. It is not easy, however, for the physicist doesn't really know just what goes on in the blocking layer of the photocell. Clearly the problem is one which demands a fundamental study completely divorced from any present considerations of a practical nature. Such a project has been initiated in our Electrical Engineering Department in connection with a broad program of study of insulators and semi-conductors—the cuprous oxide of our photocell is such—from the atomphysical viewpoint. The problem is really one of studying the laws of motion of electrons in semi-conductors; the effect of crystal versus amorphous structure; of crystal structures in which there is strong ionic binding, such as sodium chloride, versus crystal structures in which the bonding is atomic, as in sulphur; the effect of temperature on conduction and breakdown in insulators; the effect of an excess of one of the components of a crystalline compound present in the crystal. When the nature of the migration of electrons in semiconductors is better understood, when their interaction with the lattice structure is able to be formulated quantitatively, then one can attack with some hope of success the difficult barrier layer photocell problem. Whether such an attack succeeds or not, the knowledge acquired in the

course of the problem is certain to be of enormous value in a field of great practical importance, insulation research.

I come now to the last of the M. I. T. solar energy projects, one which like the previous one depends on the special properties of sunlight rather than its overall energy content. Dr. Thimann pointed out to you in his contribution our complete dependence on the process known as photosynthesis: the use by green plants of solar energy in the visible spectrum to produce carbohydrates out of carbon dioxide and water. He also emphasized the extreme complexity of the process—the fact that no one has been able to extract the essential chlorophyll and carotenoids from a plant leaf and make the reaction go in a test tube. By some process, which we have hardly begun to understand, the leaf structure succeeds in capturing the energy of sunlight and transferring it to the reaction: Carbon dioxide + Water = Carbohydrate + Oxygen, a reaction absorbing 112 kilocalories per gram atom of carbon. But to store solar energy chemically one does not have to carry out the same reaction that Nature does; any chemical reaction which absorbs energy and produces a fuel-like product capable of later combustion to return the energy for use at the proper time would be acceptable. Chemical industry has often succeeded in competing with Nature in the production of a material of desired characteristics, not by attempting a complete imitation of Nature, but by focusing attention on those properties of the natural material important to its use and imitating them with a synthetic product, perhaps chemically quite different from Nature's product.

In the photochemical field, then, a combination of sensitizers and catalysts might be attempted that would allow us to perform some relatively simple energy-storing reaction such as the decomposition of water. A major problem would be to provide suitable intermediate steps in the process in order that the relatively small energy quanta, which constitute visible light, could be used in step-wise fashion such as Nature apparently uses them in the photosynthetic apparatus of green plants. The photochemical system would probably have one of the characteristics of the photochemical system of the plant, namely heterogeneity. But the heterogeneity might be accomplished not by constructing some sort of imitation leaf, but rather for example by a colloidal solution.

Another approach to the problem is possible. We may renounce the production of metastable products or mixtures with a high content of chemical energy—fuels or explosives—and turn our attention to the utilization of the energy of the unstable intermediate products obtained in almost every photochemical reaction. Among the ways of utilizing these products is to convert their high energy content into electrical

energy. A reaction must be found in which passage from the unstable to the stable state can be made to proceed as an electrode reaction in a galvanic cell. Examples of this kind are oxidation-reduction reactions in electrolytes. The properties of such a reaction, carried out in what is known as a "photogalvanic cell," are being studied at the Institute. The system chosen consists of an organic dye, thionine, and ferrous iron in the form, for example, of a ferrous sulphate solution. The two components form in the solution a reversible oxidation-reduction system.

$$\text{(dyestuff)} + Fe^{++} \rightleftarrows \underset{\substack{\uparrow \\ \text{(colorless)}}}{\text{leukodyestuff}} + Fe^{+++}$$

Ferric iron is much stronger oxidizing agent than thionine; therefore, in the dark, all the thionine is in the form of the dye, and all the iron in the ferrous form. If, however, the mixture is illuminated by the light absorbed by thionine—i.e. visible light in the region 5000-7000 Å (green, yellow, red light), the thionine molecules are activated by light and become capable of oxidizing ferrous iron. Since the reduced thionine is colorless, the reaction is recognized by a decoloration of the solution. This bleaching proceeds to a steady state, whose exact character depends on the intensity of illumination. In this state, the velocity of the photochemical bleaching reaction is exactly compensated by that of the back-reaction restoring the equilibrium. As soon as the light is switched off, the system reverts to its original state, as shown by the following experiment. (A demonstration of reversible bleaching.) The system demonstrated represents the most light-sensitive oxidation-reduction system known so far. Its color follows the intensity of illumination to which it is subjected with a time lag of the order of one second.

Experiments have been conducted on the kinetics of this interesting photochemical process, using a photometric method for the determination of the concentration of the dye under different conditions. Of more interest in the present connection is the electrochemical effect of light in the thionine-iron system. As the composition of the solution changes due to illumination, its electrode potential is also changed; if two platinum electrodes are placed in the solution and the electrolyte surrounding one of them is illuminated while the other is kept dark, a potential difference is established between two electrodes and a current flows from the dark to the illuminated electrode. The problem of the photogalvanic effect demonstrated by this experiment has two elements: the first and simpler question is that of the electromotive force produced by a given illumination; the second is that of the current that can be drawn from such a photogalvanic cell.

So far, experiments have been concerned with the first part of the problem. The photogalvanic potential of the thionine-iron system has been measured in relation to the concentrations of all the components and the light intensity. A pronounced maximum of potential is found at a certain concentration of the dyestuff, and a strong increase in effect with decreasing acidity of the solution. From such experiments, it has been possible to develop a quantitative picture of the photogalvanic effect in satisfactory agreement with the experimental results. The next step is a study of the factors affecting current withdrawal from such a device, a phase of the program which has just commenced.

As to whether photogalvanic cells of this or similar types have practical importance as solar energy converters it is too early to hazard an opinion. Certainly their study has the merit of presenting problems in photochemistry which, while complex, are not so complex as to defy analytical treatment. In that respect they satisfy the condition which the scientist has learned to impose on himself, namely, not to ask questions of Nature which are so difficult that he cannot yet begin to understand her answer.

In summary, I have tried to point out that the best-known method of utilizing solar energy by artificial means is the relatively simple one of first converting the energy to heat; that, today, engineering data are inadequate properly to determine the value of such heat, whether for conventional use as heat or for conversion to power; that, if heat is converted to power, we are limited in possible efficiency by the second law of thermodynamics; that consequently it is necessary to turn to the fields of photochemistry and photo-electricity where theoretical limitations on expected output are less severe; that in turning to these fields it is found that the problems which arise are of so complicated a nature as to point plainly to the need for a long-range program of research into fundamental phenomena, research divorced almost completely for the time being from any considerations of a practical nature. To summarize this summary, with respect to the future of solar energy utilization, your guess is as good as mine.

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(*Continued on page 80*)

The Forty-First Annual Convention

The Forty-First Convention of the Society of the Sigma Xi was held in the Bellevue-Stratford Hotel, Philadelphia, Pa., December 30, 1940.

1. CALL TO ORDER:

The business session was called to order at 4.00 P.M. by the National President, Dr. Edward Ellery of Union College.

2. COMMITTEE ON CREDENTIALS:

The President announced a Committee on Credentials, as follows:

A. C. Hildreth, Wyoming
Florence King, Vermont (absent)
Raymond Morgan, Pennsylvania, Chairman

3. REPORT OF THE COMMITTEE ON CREDENTIALS:

The Committee received the credentials of the delegates, and reported that 59 chapters (with 78 delegates) and 14 clubs (with 16 delegates) were represented as follows:

Chapters, Clubs and Delegates:

Alabama (Seitz, Jones)
Arizona (Brown)
Brown (Mitchell)
Buffalo (Scofield)
California Institute of Technology (Anderson)
Carleton (Gatz)
Carnegie Institute of Technology (Hicks, Pugh, Smith)
Case (McCuskey)
Chicago (Olmsted)
Cincinnati (Arenson)
College of Medicine, University of Illinois (Livingston)
Colorado (Broxon)
Columbia (Pegram)
Cornell (Murdock, Wiegand, Grantham)
District of Columbia (Lambert)
Duke (Cunningham)
Florida (Wolfe)
Georgia Washington (Hansen)
Idaho (Reed)
Illinois (Stevens)
Indiana (Edmondson)
Iowa (Bodine)
Iowa State (Becker)
Johns Hopkins (Macht)
Kansas (Horr, Chapman)
Kansas State (Filinger)
Kentucky (Emmert)
Lehigh (Shook)
Maryland (Bamford, Ditman)
Massachusetts State (French, Ross)
Mayo (Bollman)
McGill (Scarth)
Michigan State (Gardner)
Missouri (Albrecht, Uber)
Nebraska (Werner)
New York (Willey)
North Carolina (Costello)
North Dakota (Weber)
Ohio State (Knauss)
Oklahoma (Dodge)
Oregon (Cressman)
Oregon State (Robinson)
Pennsylvania (Austin, Preston, Morgan)
Pennsylvania State (Sackett)
Rensselaer (Patterson, Palsgrove)
Rutgers (Starke, Hausman)
Smith (Heminway)
Southern California (Thienes)
Swarthmore (Cox)
Syracuse (Illick)
Texas (O'Byrne)
Tulane (Faust)
Union (Ellery)
Washington University (Greenman)
Wellesley (Jones, Howard, Wilson)
Wesleyan (Stearns, Sitterly)
West Virginia (Ferry, Taylor)
Wisconsin (Duggar)
Worcester (Stauffer)
Wyoming (Rahn, Hildreth)
Yale (Baitsell)

Clubs:

Brigham Young (Maw)
Colorado State (Bodine)
Denver (Zingg)
Emory (Rhodes, Redmond)
Georgie (Byrd)
Louisiana State (Ryker, Chilton)
Maine (Steinbauer)
North Carolina State College (McCutcheon)
North Dakota Agricultural College (Ray)
Oklahoma A. and M. (Webster)
St. Louis (Weber)
Texas Technological (League)
Tufts (Carmichael)
Vermont (Dunihue)

4. Minutes of the Fortieth Convention:

The account of the proceedings of the Fortieth Convention of the Society, held in Cleveland, Ohio, December 28, 1939, as published in the Quarterly, Spring 1940, was approved as printed.

5. Petitions for Charters for the Establishment of Chapters:

It was unanimously voted (as recommended by the Executive Committee) to grant a petition for the establishment of a chapter of Sigma Xi at

a. Bryn Mawr College
b. Oberlin College

6. Report of the Committee on Membership Structure:

Mr. C. E. Davies, Chairman, presented the report of the Committee, and the Convention

Voted: That the Committee on Membership Structure be continued for further study and report.

7. Report of the Committee on Lectureships:

In the absence of Professor Creighton, Chairman of the Committee, the report of the Committee on Lectureships was presented by the Secretary. The final 1941 schedules were as follows:

Dr. James Franck—"Fundamentals of Photosynthesis." Presented to the following chapters:
University of Missouri; Beloit College; University of Michigan; State College of Pennsylvania; Swarthmore College; University of Washington; University of Idaho.

Dr. Perrin H. Long—"Recent Advances in Bacterial Chemotherapy with Special Reference to the Mode of Action of Sulfanilamide and its Derivatives." Presented to the following chapters:

Mississippi State College; Louisiana State University; Texas Technological College; Washington State College; University of Utah; Brigham Young University; College of Medicine, U. of Ill.; University of Illinois; Purdue University; Ohio State University; University of Cincinnati; Brown University; West Virginia University.

Dr. I. I. Rabi—"Radio Frequency Spectra and the Magnetic Properties of Atomic Nuclei." Presented to the following chapters:

University of Rochester; University of Wisconsin; Northwestern University; Univ. of Southern California; California Inst. of Technology; Swarthmore College.

Dr. Harlow Shapley—"In Defense of the Universe." Presented to the following chapters:

Washington University; University of Nebraska; Iowa State College; University of Kansas; Kansas State College; University of Colorado; Utah State Agricultural College; University of Nevada; University of Oregon; Stanford University; University of Arizona; Tulane University; Louisiana State University; Yale University.

Dr. V. K. Zworykin—"Image Formation by Electrons." Presented to the following chapters:

Emory University; University of Alabama; University of Texas; University of New Mexico; University of Wisconsin; Northwestern University; University of Illinois; Purdue University; Michigan State College; Carnegie Institute of Technology.

8. Report of the Nominating Committee:

The Committee on Nominations was as follows:

F. M. Carpenter, Harvard; Ernest Carroll Faust, Tulane; P. H. Mitchell, Brown, Chairman.

The following officers were nominated:

For Member of the Executive Committee, to replace R. A. Gortner, whose term expires, C. E. Davies of New York (Rensselaer, 1914).

For Member of the Alumni Committee to fill the unexpired term of C. E. Davies, James R. Angell of New York (Chicago, 1903).

For Member of the Alumni Committee to replace Frederick B. Utley, whose term expires, A. Elizabeth Adams of Mount Holyoke College (Yale, 1922).

It was unanimously

Voted: To adopt the report of the Nominating Committee as presented, and to declare the nominees elected to their respective positions as named.

9. Recommendations from the Executive Committee:

1. At the April 1940 meeting of the Executive Committee, it was voted to present the following resolution to the 1940 Convention:

"Resolved: 1) To establish an annual assessment on each Sigma Xi Club, payable on January 1 of the year of the assessment to the Treasurer of the Society of the Sigma Xi for the uses of the Society.

2) That the annual assessment on each Sigma Xi Club for 1941 shall be due and payable on January 1, 1941, and that the amount of the assessment on each Club shall be 50 cents multiplied by the number of members of the Club on January 1, 1941.

It is understood that, as in the case of Chapters, the assessment will enable the Society to send the Quarterly to each Club member."

The Convention

Voted: Unanimously, to adopt the above resolution of the Executive Committee.

10. Report of the President:

(Appears on page 65, this issue.)

11. Report of the Secretary:

(Appears on page 69, this issue.)

12. Report of the Treasurer:

(Appears on page 72, this issue.)

In connection with the Treasurer's Report, the following recommendation from the Executive Committee was unanimously adopted:

Resolved: That the annual assessment on each chapter for 1941 shall be payable on January 1, 1941, and that the amount of the assessment on each chapter shall be 75 cents, multiplied by the number of members and associates of the chapter on January 1, 1941.

Resolved further: That in sending notice of the 1941 assessment to chapter treasurers, the Treasurer of the Society be instructed to advise each chapter that the assessment is to be computed solely on the basis of the number of members and associates on the membership roll of the chapter, without regard to whether said members have or have not paid current chapter dues, and to explain that this method of fixing the amount of the assessment on each chapter has been adopted by the Convention of the Society as the most equitable to all chapters.

13. The Convention adjourned at 5.45 p.m.

Meeting of the Executive Committee of Sigma Xi

December 30, 1940, Philadelphia, Pa.

A stated meeting of the Executive Committee was held at the Bellevue-Stratford Hotel in Philadelphia, Pa., December 30, 1940. The meeting was called to order by President Ellery at 9.00 a.m. Present were: President Ellery, Secretary Baitsell, Treasurer Pegram, Messrs. Lund, Shapley, Anderson, Jordan, Durand, Utley; and, by invitation, Mr. Davies of the Alumni Committee, Chairman of the Committee on Membership Structure; Mr. Sweet of the Alumni Committee; and Professor Creighton, Chairman of the Committee on Lectureships.

1. Reports of Officers:

The annual reports of the President, Secretary, and Treasurer, prepared for submission to the National Convention, were presented for preliminary consideration. In connection with the report of the Treasurer, the President raised the question as to whether or not the Committee would favor the use of income from all the in-

vested funds of the Society for support of research.

It was

Voted: To ask the President, Secretary, and Treasurer to study the proposal and report at the April meeting.

It was also

Voted: To present to the Convention, with recommendation for favorable consideration, the usual resolution regarding annual assessment of chapters.

2. Formal Petitions for the Establishment of Chapters:

It was

Voted: To present to the 1940 Convention, with recommendation for favorable action, printed petitions from faculty groups for the establishment of chapters at Oberlin College and Bryn Mawr College.

3. Informal Petitions for the Establishment of Chapters:

The Secretary presented additional data from the following institutions, whose requests for the establishment of a chapter have been under previous consideration by the Committee: University of Vermont, Utah State Agricultural College, Illinois Institute of Technology, Texas Technological College, Louisiana State University. Each of these requests was discussed in detail, and it was

Voted: That further action be postponed until the April meeting of the Committee.

4. New Inquiries about Chapters:

The Secretary presented preliminary information from faculty groups at the following institutions, who are now asking for the establishment of chapters: Marquette University, Tufts College, Polytechnic Institute of Brooklyn, and Emory University. In each case it was

Voted: To ask the faculty group to prepare the official information questionnaire and to present ten copies to the national officers for study before the April meeting of the Committee.

5. Oregon Situation:

The conditions relative to Sigma Xi at the University of Oregon have been called to the attention of the Committee at various times in recent years. In this connection Dr. L. S. Cressman of the University of Oregon, who was present in Philadelphia, appeared before the Committee and made a statement of the situation as he saw it. It was

Voted: That further action be postponed until the April meeting.

6. Standards of Institutions requesting Charters:

It was

Voted: That as a matter of general procedure in connection with institutional standards, the Executive Committee be furnished, when available, with the reports of the Engineers Council for Professional Development and the Association of American Universities on all institutions brought before the Committee for consideration.

7. Reports of Committees:

a. Committee on Publicity:

It was

Voted: That an appropriation of $200 be made to Science Service for the year 1941, with the understanding that Dr. Shapley would report to the December meeting of the Committee as to the advisability of continuing the appropriation thereafter.

b. Committee on Membership Structure:

Mr. Davies presented the report of the activities of the committee. It was

Voted: That the report of the Committee on Membership Structure be accepted and the two recommendations be presented to the Convention with recommendation for favorable action.

c. Committee on Lectureships:

Dr. Creighton presented the report of the National Lectureships for 1941, and the probable lecturers for 1942 (see page 1, this issue). In view of the overcrowded 1941 schedules, it was

Voted: To invite the lecturers for the 1942 series on a possible three-week basis.

d. Committee on Grants-in-Aid of Research:

The results of the circularization of the alumni in 1940 were considered in connec-

tion with a possible circularization for 1941. It was

Voted: That the circularization be continued in 1941.

8. Insignia and Diplomas:

The attention of the Committee was called to the fact that not all the chapters are supplying official diplomas to the initiates. It was

Voted: To present the following resolution to the Convention:

Resolved: That the Convention request the Secretary to notify the chapters that this Convention has voted that each new member or associate should, upon initiation, be given an official certificate of membership or associateship by his chapter.

It was further

Voted: That the price of diplomas should be reduced to 10 cents each, without engrossing, and 25 cents each, with engrossing.

The Secretary called the attention of the Committee to the fact that the associate emblem now being supplied is not in the form of a key as specified in the Constitution, Article VII, Sec. 1 (b); and further, that several requests have been received for a medium size member emblem. It was

Voted: To grant the Secretary power, if it seems advisable to him, to add the correct associate emblem and the medium size member emblem to those now available.

9. Sigma Xi Quarterly:

The present status of the Editorial Board was discussed, and it was

Voted: That the present policy be continued for the time being.

The question of publication of the National Sigma Xi Lectures in the Quarterly was discussed at length. The Committee favored such publication on an experimental basis, with the idea that the lectures could be published in the Quarterly in such a form that they could later be reprinted for use in Science in Progress at much less cost than at present.

The Committee considered the possibility of changing the title of the Quarterly, with the idea that a broader title might result in a wider appeal. No formal action was taken, but the general opinion of the Committee was that possibly a better title might be found.

10. Closer Contact of Initiates with the National Organization:

The Committee was asked to consider the question of furnishing a copy of the Quarterly and the Constitution to each initiate, to be handed him by the chapter at the time of his initiation. It was

Voted: That the chapter secretaries be supplied with sufficient copies of the Constitution and the Initiates Number of the Quarterly for distribution to each initiate at the time of his initiation.

11. Time of the Spring Meeting:

It was

Voted: That the Spring meeting of the Executive Committee be called for Wednesday, April 30, at 1.00 p.m. in the Cosmos Club, Washington, D. C.

President's Report for 1940

In this report on the state of the Society of the Sigma Xi for 1940 by your president, a little look backward will clear the longer look forward which you and your chapters are asked to take. The first of the society's movements in the promotion of research was naturally the spread of chapters among institutions where research was in actual progress or apparently possible, and the consequent growth in the number elected to membership on the basis of actual investigation. The second movement was the creation of a sub-grade of members, called "associates," by which prospective research ability among undergraduates who had not had opportunity for scientific investigation was recognized. In the third movement the society entered

the field of scientific periodicals and issued the SIGMA XI QUARTERLY, which has had continuous publication since 1912. With a fourth movement began the society's financial support of research, at first in the form of fellowships to one or two individuals, then in the presentation of research prizes, and now in the award of grants-in-aid in small sums to a number of applicants. Closely connected with that, the fifth movement of the society in the promotion of research was the establishment of permanent funds, the income from which is segregated and added from time to time to the sum available for grants-in-aid. The sixth movement introduced the maintenance of the national Sigma Xi lectures, the fifth series of which begins in the coming month. And the seventh and latest movement of our great Society in the promotion of research is the publication, in book form, of these national lectures under the appropriate title "SCIENCE IN PROGRESS."

To quote from the secretary's report for 1939, "The Society of the Sigma Xi is a living organism. Growth is inevitable where there is life."

Turning from that brief but noble retrospect, what of today? The society is moving. How? What of tomorrow? The society will continue to move. To what?

First. Growth in Chapters:

The limit of such growth is already in sight. There are now 80 chapters. This convention may grant two more charters. The chapter institutions are obviously splendidly equipped for science, have large financial resources, produce an impressive research output. We have 35 clubs in as many institutions, some of them potential chapters. They are our most promising field for chapter growth. There is a student body approximating 87,000 in number, with about 6,000 in the combined faculties, not all of them in science of course. Twenty of the clubs report a total membership of 727, with 526 papers published in 1939 and 1940. The endowments of six institutions range from two and a half to ten million—and others have state or city financial support. Probably not all the clubs will become chapters, but suppose they do. Sigma Xi will then be in 117 educational institutions in this country. Look over the list of the remaining 600 or so. From present prospects Sigma Xi will go into very few. Sigma Xi is approaching a limit in the growth of chapters as far as educational institutions are concerned.

Has the time come for the Society to consider the establishment of chapters in other than educational institutions, for instance, industrial research laboratories? Such an expansion would fall within the definition in our constitution which authorizes the organization of chapters in research institutions as well as colleges and universities, provided they have the same unrestricted rights of publication as educational institutions. There are already chapters in Mayo Institute and the University of Illinois College of Medicine, which are "research" as well as "educational" institutions. But there are many industrial and other research laboratories from which important scientific publications frequently issue, manned by Sigma Xi members and where there are large groups of young workers exhibiting and developing marked ability as investigators and who on that basis are eligible to membership in our Society—such places as the Institute for Cancer Research, Rockefeller Medical Institute, the General Electric Research Laboratory, the Mellon Institute, the Bell Telephone Company, the Armour Company, National Aniline, Atlantic Refining, DuPont, Eastman, and a score of others. The money expended annually by these laboratories (estimated at more than $200,000,000) and the number of workers in them (said to total more than 50,000) are impressive. Science in industries as in universities does not wait for something to turn up. Science in both is constantly turning something up. Workers in industrial research laboratories belong to us by virtue of their careers, quite as much as do science faculties and students of our universities. Here to all appearances is a

promising and fruitful field for expansion of our chapter growth.

Second. Growth in number of constituents:

Sigma Xi is approaching the peak of the increase of members and associates annually elected. In the next decade it may actually be confronted by a decrease. In the last five years there has been a definite falling off in the number of boys and girls in our secondary schools. That means eventually a smaller number eligible for admission to college, and a consequent smaller number of candidates for election into Sigma Xi.

Another movement affecting the growth of our constituency is in the society itself —the large group of our chapters, about half of them, which do not elect undergraduates at all, or a negligible number. The findings of our Committee on Membership Structure, which will be reported to you later at this convention, will startle you as they have those of us who have had a preview of the situation. In other words, the society itself is curtailing its growth in constituency.

Of course Sigma Xi is not committed to any given annual number of additions of members and associates, but it is interesting to face the reality in view of the fact that the initial movement of the society in the promotion of research was the constant rejuvenation of our ranks of investigators, a movement that has continued without interruption through 54 years of its life. Then ask what of tomorrow? Are there other fields within our present system of higher education which the originality, ingenuity, inventiveness of its workers invite Sigma Xi to enter? Our constitution states "the object of this Society shall be" (that ought to be changed at once to "is") "to encourage original investigation in science, pure and applied." Is science the only field in the curricula of our institutions in which original investigation is carried on? Are not our colleagues in history, literature, economics, government, also doing research? Why not change our constitution to read, "the object of this Society is to encourage original investigation." Sigma Xi is the one organization in our educational system that limits eligibility to membership to ability to discover. Not even our older, highly revered, sister honorary society, Phi Beta Kappa, makes original investigation a prerequisite to membership. In that organization scholarship as measured by academic grades is the basis of eligibility, not actual work of investigation. Aren't investigators in those fields worthy of recognition simply because they are investigators, not merely students of high rank in the registrar's office? I know this suggestion startles you. I also know that the Society of Sigma Xi stands clearly for original investigation.

Third. The Sigma Xi Quarterly:

The first issue was in 1912, and for many of the beginning years the contents were limited to reports of chapter activities with occasional articles on Sigma Xi administrative problems and policies, less frequently on topics concerned with results of research. In 1913 the subscription list numbered 1,700. The latest issue was mailed to 26,000 individuals and libraries, 21,000 being on the regular mailing list. It contains in addition to important official announcements to members and to the world of science in general, three timely articles by scientists of note. Such has been the growth of the periodical, and such the change in contents. Within the last year or two abstracts of some of the articles have been reproduced in *Science Digest*. To go back to what we used to do with our periodical is unthinkable. And to stop with what we are now doing would be a betrayal of the spirit of growth in importance and influence which is the impressive characteristic of the Society of the Sigma Xi. Hence the appointment of a Committee on the QUARTERLY, and its report in the Spring 1940 issue. The time has come to enlarge the QUARTERLY in number of pages of each issue, to include in its contents survey articles for the general scientific public as well as papers which set forth research results in specific

fields and to change the name to one of more definite significance.

Fourth. The Sigma Xi financial support of research:

Obviously such support is limited only by restricted resources. Our present grants-in-aid movement began in 1921, and with the exception of one year has been continuous since its inception. The total sum distributed in that period is in excess of $40,000, or an average of $2,000 a year. We can do better. The source of our grants-in-aid funds, namely members and associates not connected with chapters, has yielded thus far only a small fraction of what is potentially available. About 15,000 Sigma Xi members and associates, now connected with chapters, are assessed by the national convention at the rate of 75 cents per individual. In 1939 this resulted in a total of approximately $8,500—used for expenses of administration. There are 25,000 members and associates, not connected with chapters, who have no financial obligation to the society in which they accepted membership. Last year some 2,000 of this large number contributed voluntarily to our grants-in-aid fund something like $3,000. If the remaining 23,000 had had the same obligation which active members and associates carry, the society would have been able to distribute over $17,000 in support of research. Or if each one of the total 25,000 was under obligation to pay to the national treasurer only 25 cents, Sigma Xi would have over $6,000 for use in promoting research. And why not? Why should financial obligation to the Society be limited to those who are active in chapters? Why should not every Sigma Xi member and associate of the Society be under the same obligation? The annual convention levies an assessment on active members and associates. The constitution fixes an initiation fee of $1.00 for each newly elected member or associate. Why should not the constitution fix as part of their obligation to the Society annual dues for all those members and associates not connected with the chapter institutions. Last year initiation fees to the national organization totaled over $2,000, and most of the initiates left the institution after their initiation. Why should they not continue to pay into the Society $1.00 a year? Think what that would mean in Sigma Xi's promotion of research, even in the first year of it—and what an immense impetus to research would be made possible as the years passed.

The Society now limits its awards of grants-in-aid to those who apply. There are additional and effective ways of using our funds to further research, especially if available funds increase. The society can support particular research projects—human diseases, mutation of elements, atomic energy, nutrition—there are many such, successful research which would add to human physical comfort and convenience and further free the human spirit. The Society could allot to institutions where we have chapters various sums from time to time to be used at the discretion of heads of science departments. Chapters could be given grants for use as research prizes.

With increased funds the Society would be able to participate actively in the relief of our European colleagues now so harassed and circumscribed. The immediate need for rescue and evacuation of both brilliant and promising scientists is tragic enough, but there will still be need for apparatus and books, perhaps even for bread, in the adjustment years that will follow the present dark age—a magnificent and inviting opportunity for our Society to spread its work of promoting research.

Fifth. Sigma Xi Permanent Funds:

Today the only permanent fund of the Society is the so-called Semi-Centennial Fund of $15,050. At the close of 1939 the treasurer reported cash and securities carried at cost to the amount of $28,161. From this sum the permanent fund could be increased to $25,000 or $30,000—perhaps should be. Possibly interested friends

of our great Society should be approached for further gifts of this character. Your president holds, however, that the accumulation of a permanent fund is not of equal importance with the increase of sums for current distribution in the support of research.

Sixth. Sigma Xi National Lectures:

The fifth of this series will open next January and close in April. There have been more than 70 requests for this 1941 series, as compared with 50 for 1940, 39 for 1939, 31 for 1938, and 27 for 1937. The itineraries of the lecturers cover the United States, their travelling expenses are met from the general funds of the Society, and their honoraria are paid by the chapters and clubs engaging them. It is clearly evident from the five years' experience that this movement is favorably recognized and accepted. The question at once arises, shall it be made permanent and expanded? At present, the number of lecturers is limited to five, and the period in which each is available is about two weeks. If the Society's income is increased, we could appoint more lecturers, under the same financial arrangements as at present; the lectures could be allotted among the chapters and clubs by the Society's Committee on Lectures; a fixed stipend could be named for the lecturers. Should our Committee on Lectures be asked to consider such important questions as these, for report to our 1941 Convention?

Seventh. The Sigma Xi Publication— SCIENCE IN PROGRESS:

This is the collection in book form of the Sigma Xi national lectures. There are now two volumes in the series. The first was published in May of 1939, and to date some 1,500 copies have been sold. The second appeared last month and already a number of orders for it have been filed with the national secretary, and doubtless also with the publishers. Both volumes were recognized by the Scientific-Book-of-the-Month Club as the leading science publication of the month in which each appeared. The movement is too young to afford a basis for judgment about possible expansion. The single question that has arisen in connection with it is this: should these lectures have their first published appearance in our SIGMA XI QUARTERLY for the benefit of our entire membership, and then be gathered into a volume to be issued by the Society itself?

All of this is worth pondering by our constituent chapters. Your president requests that the full report be discussed at some early chapter meeting. He expects to visit chapters during the spring and fall of the coming year, with the sole object of considering with the Society's active constituency these and other matters that are of moment in the great Society of the Sigma Xi.

EDWARD ELLERY.

Secretary's Report for 1940

In accordance with the vote of the last annual Convention, the national headquarters was transferred during the latter part of June to its new location in the Osborn Zoological Laboratory, Yale University. Thanks to efficient planning by the retiring Secretary, the transfer was made without interruption to the business of the Society. No credit for this is claimed or deserved by the incoming Secretary, as he was on the Pacific coast in connection with the installation of the new chapter at the University of Southern California and attendance at the A. A. A. S. meetings at Seattle. Returning to New Haven a few days later everything was found to be serene at the national headquarters, with business as usual under way. The administrative officers at Yale, both of the University as a whole and of the Laboratory,

have warmly welcomed Sigma Xi to its new quarters, and have rendered every possible assistance, for which all of us associated with the administrative affairs of our organization are profoundly grateful.

After some months' close association with the business of the Society, the new Secretary can vouch for the truth of the situation at national headquarters as emphasized in previous reports by Secretary Ellery, namely, it is a busy place; possibly never more busy than it has been during the fall months just passed with the publication of ***Science in Progress***, Series II, the Autumn issue of the QUARTERLY, the details of the Grants-in-Aid Committee, the Committee on Membership Structure, and the arrangements for the 1941 series of Sigma Xi Lectureships to be attended to, in addition to the daily routine of an organization with some 80 chapters, 40 clubs, and 40,000 enrolled members.

It may be necessary in order to handle the business of the Society efficiently that additional secretarial assistance be provided. Handling the records alone, in accordance with the routine established by Secretary Ellery, appears to call for a full-time Clerk of Records. It is for the national organization, acting through its Executive Committee, to determine just how much detailed work should be continued in this important field in the endeavor to maintain contact with the constantly expanding membership list. Fortunately, the valuable report of the Committee on Policy under the Chairmanship of R. A. Gortner is available as a basis for possible changes in this office.

Reference may now be made to a number of specific items of importance to the organization.

1. Two new chapters have been installed during the year, in accordance with the vote of the Columbus Convention:

At the Virginia Polytechnic Institute, Blacksburg, Va., on April 5; the installing officers were the National President and Secretary.

At the University of Southern California, Los Angeles, Calif., on May 24; the installing officers were the National Secretary and Dr. C. D. Anderson of California Institute of Technology, a member of the Executive Committee.

Reports of these installations have already appeared in the QUARTERLY. It remains only to say that both of the new chapters have been started under the most favorable conditions, and give every evidence of contributing greatly to their respective institutions and to the Society of the Sigma Xi. Several institutions are under consideration by the Executive Committee at the present time with reference to their qualifications for the establishment of chapters. Also several new Sigma Xi clubs have been, or are now in the process of being, organized at Tufts College, Queens College, and Baylor University.

2. During the past year, as you will see from the reports made to the Committee on Membership Structure, there were a total of 3,485 elections to the Society, with six chapters not reporting. Of these, 1,755 were members, and 1,568 associates, with 149 promotions from associate to member. These figures compare with those of previous years as follows:

	1940	*1939*	*1934*	*1929*	*1924*
Members	1,755	1,651	1,380	1,070	739
Associates	1,568	1,496	1,072	827	442
Promotions	149	127	79	106	27

This comparison shows the very rapid annual growth of Sigma Xi that is taking place. The reports received by the Committee on Membership Structure have also revealed that full reports of initiations have not been made to the National Headquarters by some of the Chapters. It is hoped that this situation may be corrected at once as it necessarily makes the national records incomplete.

3. This year the Executive Committee voted to circularize 10,000 of the Alumni for contributions to the Alumni Research Fund. The circularization resulted in contributions amounting to $2,752.19. By vote of the Executive Committee at the

April meeting, $600.00 interest received from the investments of the Semi-Centennial Fund was added to the contributions, making the total sum available for grants-in-aid, $3,352.19. The report of the Grants-in-Aid Committee, and a complete list of contributors, were printed in the Autumn issue of the QUARTERLY. The total of $3,350.00 was awarded to 14 applicants, as compared with last year's award of $2,180.00 to 12 applicants.

It is felt by members of the Alumni Committee that the cost of the circularization, which is paid from the general funds of the Society, is much too high, and that, therefore, some better method for securing contributions for research from the Alumni members must be devised.

4. During the 28 years of its publication, the SIGMA XI QUARTERLY has grown from a small pamphlet largely devoted to chapter reports and minutes of meetings of the Executive Committee and Convention, to an important scientific periodical. The Autumn 1940 issue contained four scientific articles, and was distributed to 5,000 alumni, as well as to the regular subscription list. Special subscription rates were offered to Alumni members of one year for $1.00, two years for $1.50, and five years for $3.00. To date this has resulted in 41 subscriptions from alumni, and additional ones continue to come day by day.

In accordance with the report of the Committee on QUARTERLY, adopted last year, a committee is making plans for further development and improvement of this valuable magazine.

5. Announcement of the 1941 Sigma Xi National Lectureships was made to the chapters during the summer and in the Autumn issue of the QUARTERLY. The lecturers this year are Dr. James Franck of the University of Chicago, Dr. Perrin H. Long of the Johns Hopkins Hospital, Dr. I. I. Rabi of Columbia University, Dr. Harlow Shapley of the Harvard College Observatory, and Dr. V. K. Zworykin of the RCA Electronic Research Laboratory in Camden, New Jersey. The requests for lectures by this distinguished group of scientists has been overwhelming, 75 in all, but, unfortunately, the limited time at the disposal of the lecturers has made it impossible to fill all the chapter requests. After careful planning and consultation with the lecturers, arrangements have been made for lecturers to appear at 50 institutions. It is a matter of great regret to the lecturers themselves and to all of us who are concerned with the National Sigma Xi Lectureships that every request could not be granted.

6. The National Sigma Xi Lectureships for 1937 and 1938 were published in the Society's volume *Science in Progress*, Series I, which resulted in a sale of 1,575 copies. On December 3 of this year Series II of *Science in Progress* was published, containing the Lectureships for 1939 and 1940. 468 copies have been sold to date. It is probable that the Lectureships will continue to be published every two years in the *Science in Progress Series*. Both volumes have been chosen by the Scientific Book-of-the-Month Club, and both volumes deserve far wider distribution among the Sigma Xi membership than has so far been achieved. The substantial discount now made available to members and associates of Sigma Xi should result in greatly increased sales.

National Headquarters is at your service. Every effort will be made to handle the business of the Society quickly and efficiently.

GEORGE A. BAITSELL.

Report of the Treasurer for 1940

Operating Statement for the Year Ended December 31, 1940, for General Conduct of the Society

Income

Chapter assessments	$ 9,338.50	
Initiation fees	3,521.00	
Installation fees	100.00	
Sale of insignia	10,525.95	
Interest income	976.27	
Lecturers' stipends	2,450.00	
Alumni contributions for research	2,749.74	
Miscellaneous income	938.52	
Diploma fees	677.76	
Science in Progress income	315.40	
Subscriptions to Quarterly	94.00	
Gross income		$31,687.14

Expenditures

Secretary's office (total $6,212.27)		
Secretary's stipend	$ 1,800.00	
Assistance	2,672.00	
Supplies	1,740.27	
Treasurer's office (total $264.30)		
Assistant	150.00	
Postage, supplies, etc.	45.12	
Auditing 1939 books	30.00	
Custodian account	26.68	
Treasurer's bond	12.50	
Officers' travelling expenses	1,174.22	
Quarterly (four issues)	3,079.43	
Circulation of alumni for research contributions	435.65	
Engrossing charters	98.15	
Lecturers' stipends	2,450.00	
Lecturers' expenses	1,326.95	
Science Service	200.00	
Grants-in-aid of research	2,750.00	
Diploma expense	282.28	
Insignia expense	7,140.55	
Removal of Secretary's office to New Haven	319.42	
Books, *Science in Progress* for alumni contributors	420.40	
Investment expense	28.50	
Miscellaneous expense	168.40	
Total expenditures		$26,350.52
Operating surplus for the year		$ 5,336.62

Disposition of Operating Surplus

Alumni Fund for Research:			
Alumni contributions		$ 2,749.74	
Interest on Semi-Centennial Fund		602.00	
		$ 3,351.74	
Less: Grants-in-aid of Research for 1940*	$ 2,750.00		
Less: Books, *Science in Progress*	420.40		
		3,170.40	
Surplus allocated to Alumni Fund			$ 181.34
General Funds:			
Balance of surplus allocated to General Funds			5,155.28
			$ 5,336.62

* *Payments on Grants for Research:*

Duncan McConnell (1939-40)	$ 150.00	F. T. Addicott (1940-41)	200.00
Freeman D. Miller (1939-40)	50.00	A. C. Giese (1940-41)	100.00
Dorothy M. Wrinch (1940-41)	500.00	Lewis H. Kleinholz (1940-41)	100.00
Richard A. Fennell (1940-41)	50.00	H. M. Huffman (1940-41)	400.00
W. J. Luyten (1940-41)	150.00	Mary L. Willard (1940-41)	250.00
R. W. Fautin (1940-41)	300.00		
E. P. Mumford (1940-41)	500.00		$2,750.00

Balance Sheet as of December 31, 1940

Assets

Cash:		
Checking accounts	$12,702.86	
Custodian account	11,812.50	
		$24,515.36
Securities owned (carried at cost—see schedule following)		24,670.79
		$49,186.15

Liabilities

Accounts payable		$ 816.25

Funds

General Funds:		
(Cash and securities carried at cost)		
Balance January 1, 1940	$28,161.34	
1940 surplus allocated to General Funds	5,155.28	
		$33,316.62
Semi-Centennial Fund		15,050.00
Alumni Fund:		
1940 surplus allocated to Alumni Fund	$ 181.34	
Less deficit as at January 1, 1940	178.06	
		3.28
		$49,186.15

Investment Account

Schedule of Securities Owned, Carried at Cost

$1,000	Amer. Tel. & Tel. Co. 5½% (1943) bond at	$ 991.94
$1,000	St. Louis & San Francisco Railway 4% (1950) bond at (certificate of deposit)	796.35
$1,000	Baltimore & Ohio Railway 5% (2000) bond at	955.00
$1,000	Philadelphia Company 5% (1967) bond at	979.50
$1,000	Erie Railroad Company 5% (1967) bond at	947.00
$1,000	Southern Railway Company 6% (1956) bond at	1,152.00
$1,000	Philadelphia Company 5% (1967) bond at	997.00
$1,000	Canadian Pacific 5% (1954) bond at	1,010.00
$1,000	U. S. Treasury 4% (1954) bond at	999.06
$1,000	U. S. Treasury 3% (1955) bond at	942.50
$1,000	U. S. Treasury 3% (1955) bond at	942.50
$1,000	U. S. Treasury 3% (1955) bond at	942.50
$1,000	U. S. Treasury 3⅛% (1946/49) bond at	1,069.07
$1,000	U. S. Treasury 3⅛% (1946/49) bond at	1,069.06
$1,000	U. S. Treasury 3⅛% (1946/49) bond at	1,069.06
$ 200	New York City 4% (1941) bond at	198.50
$ 200	New York City 4% (1942) bond at	198.50
$ 200	New York City 4% (1943) bond at	198.50
$1,000	Consumers Power Co. 3½% (1965) bond at	1,057.50
$1,000	Consumers Power Co. 3½% (1965) bond at	1,057.50
$1,000	Edison Elec. & Illum. Co. 3½% (1965) bond at	1,071.25
$1,000	Edison Elec. & Illum. Co. 3½% (1965) bond at	1,071.25
$1,000	Consolidated Edison Co. 3¼% (1946) bond at	1,047.50
$1,000	Consolidated Edison Co. 3¼% (1946) bond at	1,047.50
$1,000	Consolidated Edison Co. 3¼% (1946) bond at	1,047.50
$1,000	Southern Pacific Co. 4½% (1969) bond at	905.75
$1,000	Southern Pacific Co. 4½% (1969) bond at	907.00
		$24,670.79

All companies continue to pay interest on their bonds except the Erie Railroad; the St. Louis & San Francisco Railway and the Baltimore & Ohio Railway paying part only.

Schedule of Securities Redeemed in 1940

$ 200	New York City 4% (1940) bond at	$ 200.00
$1,000	Southern California Edison Co. 3¾% (1960) bond	1,050.00
$1,000	Southern California Edison Co. 3¾% (1960) bond	1,050.00
	Included in cash—custodian account	$ 2,300.00

George B. Pegram, *Treasurer.*

February 18, 1941.

Auditors' Statement

We have audited the accounts of the Treasurer of the Sigma Xi Society for the year ending December 31, 1940, and have found that all income as contained in the records was duly accounted for and that disbursements were supported by proper vouchers. The securities listed above were verified by certificates from the Custodian, namely, The Corn Exchange Bank Trust Company. We certify that the foregoing Balance Sheet and Statement of Income and Expenditures are correct, are on a cash basis, and fairly present the operations for the year and the financial position of the Society as of December 31, 1940.

J. T. Finneran,
Frank X. Farr,
Auditors.

February 18, 1941.

Science Makes Us Grow

(*Concluded from page 48*)

Of the three Promethean gifts of science, it was the greater variety of life which Francis Bacon saw as he wrote in his "New Atlantis":

> The end of our society is the knowledge of causes, and the secret motions of things, and the enlarging of the bounds of human empire to the effecting of all things possible.

It was its responsibility for man's social evolution which led Sarton to describe the growth of science as the central thread along which may be traced the biography of mankind. To the scientist himself comes the satisfaction that with his new knowledge an addition has been made to man's heritage which not only is permanent but is a seed that will grow from more to more. With Democritus he can truly say:

> I would rather learn the true cause of one fact than become king of the Persians.

Having eaten of the fruit of the tree of knowledge we have in a new sense become as gods, with greater power for good and evil. We have been cast once more from the paradise of a well-established, traditional life. Punishment for our errors is by an angel with a keener, more flaming sword as we live the hard life of new responsibilities. And so we are forced to search for greater wisdom to govern our greater powers. If a brighter paradise is to be regained, it is that of the joy of the struggle toward greater manhood.

Contributors to Alumni Research Fund—1941

This list of contributors is incomplete. The remaining names will be published in the Summer issue.

C. G. Abbot (District of Columbia)
Henry H. Abbott (Ohio State)
A. Elizabeth Adams (Yale)
William A. Adamson (Cornell)
Charles A. Alexander (Cornell)
Frank N. Allan (Mayo)
Elda E. Anderson (Wisconsin)
Earl L. Arnold (Cornell)

Herman Babel (Yale)
Mervin K. Baer (Michigan)
Hugh P. Baker (Mass. State)
Wilfred H. Baker (Syracuse)
Edith L. Ballard, M.D. (Cornell)
DeWitt D. Barlow (Penn.)
Elliott P. Barrett (Columbia)
Walter I. Barrows (Worcester)
Edward Bartow (Iowa)
Edwin Bartunek (Nebraska)
Grace E. Bates (Brown)
Zilpha C. Battey (Illinois)
William I. Battin, Jr. (Swarthmore)
Gerald R. Beezer (Univ. of Washington)
LaMar N. BeMiller (Purdue)
Mary A. Bennett (Chicago)
Mary Woods Bennett (California)
Stanley U. Benscoter (Illinois)
D. Berger (Penn.)
S. G. Bergquist (Michigan State)
Anton H. Berkman (Texas)
Joseph Bernstein (Yale)
William Biederman (Cornell)
C. H. Bierbaum (Cornell)
H. E. Bishop (Union)
Clarence M. Blair (Yale)
Dr. Homer Blincoe (Kansas)
R. J. Block (Yale)
Ernest K. Bloss (Worcester)
V. L. Board (Missouri)
Harry C. Boardman (Illinois)
Marston T. Bogert (Columbia)
Julia Wells Bower (Chicago)
Nathan A. Bowers (Stanford)
Harvey B. Bowman (Cornell)
T. A. Boyd (Ohio State)
Charles J. Brand (Minnesota)
Gladys L. Brandt (Chicago)
Clarence E. Breckenridge (Cornell)
Clarence A. Brock (Worcester)
Ludvig G. Browman (Montana)
W. D. Buckingham (Case)
Edward Budnitz, M.D. (Yale)
Leroy H. Burns (Yale)
Frank Burton (Michigan)
Elizabeth Butler (Chicago)

William H. Cady (Brown)
Edward M. Cameron (Union)
Clifton C. Carlson (Minnesota)
Henry E. Carlson (Worcester)
Emmett B. Carmichael (Alabama)
David E. Carpenter (Worcester)
Harriet Carter (Chicago)
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Texas Technical College—W. S. Glock, Pres.; W. W. Yocum, V.-P.; J. Q. Sealey, Sec.; ————, Treas.

University of Montana—F. O. Smith, Pres.; G. D. Shallenberger, V.-P.; C. W. Waters, Sec.; ————, Treas.

Peking, China—K. P. Young, Pres.; H. C. Chang, V.-P.; P. P. T. Sah, Sec.; P. P. T. Sah, Treas.

Wichita—W. A. Ver Wiebe, Pres.; C. C. McDonald, V.-P.; B. Cooper, Sec.; B. Cooper, Treas.

Ohio University—D. B. Green, Pres.; C. L. Dow, V.-P.; A. C. Anderson, Sec.; A. C. Anderson, Treas.

University of New Mexico—R. E. Holzer, Pres.; G. V. Martin, V.-P.; L. S. Gill, Sec.; L. S. Gill, Treas.

University of Kansas City—K. L. Mahoney, Pres.; L. L. Eisenbrandt, V.-P.; C. W. Sondern, Sec.; C. W. Sondern, Treas.

Polytechnic Institute of Brooklyn—R. E. Kirk, Pres.; C. C. Whipple, V.-P.; W. H. Gardner, Sec.; W. H. Gardner, Treas.

Marquette University—H. P. Pettit, Pres.; D. R. Swindle, V.-P.; J. F. H. Douglas, Sec.; ————, Treas.

Milwaukee—Mary Pinney, Pres.; ————, V.-P.; M. J. Martin, Sec.; ————, Treas.

Lewis Institute—M. A. Countryman, Pres.; B. S. Radcliffe, V.-P.; L. T. Anderson, Sec.; D. L. N. Hedrick, Treas.

Mississippi—V. A. Coulter, Pres.; G. W. Nicholson, V.-P.; ————, Sec.; ————, Treas.

SIGMA XI CLUBS AND OFFICERS—*Continued*

Vermont—P. A. Moody, Pres.; H. B. Pierce, V.-P.; H. G. Millington, Sec.; H. G. Millington, Treas.

Utah State Agricultural College—L. H. Blood, Pres.; R. P. McLaughlin, V.-P.; D. W. Thorne, Sec.; D. W. Thorne, Treas.

Brigham Young University—W. B. Hales, Pres.; B. Harrison, V.-P.; A. J. Johanson, Sec.; A. J. Johanson, Treas.

Beloit College—C. Welty, Pres.; ————, V.-P.; N. Bennington, Sec.; N. Bennington, Treas.

Alabama Polytechnic Institute—B. T. Simms, Pres.; R. Allen, V.-P.; H. R. Albrecht, Sec.; H. R. Albrecht, Treas.

Emory University—J. G. Lester, Pres.; H. Blincoe, V.-P.; E. Papageorge, Sec.; W. B. Redmond, Treas.

North Carolina State College—B. R. VanLear, Pres.; F. H. McCutcheon, V.P.; O. Veerhoff, Sec.; O. Veerhoff, Treas.

Hawaii—C. H. Edmondson, Pres.; J. H. Beaumont, V.-P.; S. S. Ballard, Sec.; S. S. Ballard, Treas.

Mississippi State College—C. H. Ragland, Pres.; F. P. Welch, V.-P.; J. F. Locke, Sec.; J. F. Locke, Treas.

University of Nevada—W. D. Billings, Pres.; I. J. Sandorf, V.-P.; L. R. Williams, Sec.; L. R. Williams, Treas.

Queens College—Frank Schneider, Pres.; ————, V.-P.; Hugo Swenson, Sec.; Hugo Swenson, Treas.

Tufts—R. L. Nichols, Pres.; R. L. Carpenter, V.-P.; N. Y. Wessell, Sec.; A. H. Howell, Treas.

Santa Barbara State College—F. T. Addicott, Pres.; ————, V.-P.; Emily Lamb, Sec.; Emily Lamb, Treas.

Report of the Committee on Membership Structure

At the 1940 Convention and Executive Committee meeting, considerable attention was given to the highly important preliminary report of the Committee on Membership Structure, as presented by Mr. C. E. Davies, Chairman. It is apparent that this report should be as widely circulated as possible among the membership; it is, therefore, being printed as a supplement to this issue of the Quarterly. It is hoped that every chapter will study the report carefully and express their opinion to the National Headquarters as to future course of action, so that the Committee will know their feeling in the matter.

Artificial Converters of Solar Energy

(*Concluded from page 60*)

Epstein, Leo F., Karush, F., and Rabinowitch, E. A Spectrophotometric Study of Thionine. *Jour. Opt. Soc. America, 31*, 1941.

Hottel, H. C., and Woertz, B. B. The Performance of Flat-Plate Solar Heat Collectors. Presented at a meeting of the Am. Soc. Mech. Engrs., Atlanta, April, 1941.

Rabinowitch, E. The Photogalvanic Effect. I. The Photochemical Properties of the Thionine-Iron System. *Jour. of Chemical Physics, 8*, 1940.

————. The Photogalvanic Effect. II. The Photogalvanic Properties of the Thionine-Iron System. *Jour. of Chem. Physics, 8*, 1940.

SIGMA XI - STUDY OF MEMBERSHIP STRUCTURE

MEMBER

NAME OF CHAPTER	NO.	PROFESSORS, INSTRUCTORS, ETC 1940	1939	1934	1929	1924	GRADUATE STUDENTS 1940	1939	1934	1929	1924	UNDERGRADUATE STUDENTS 1940	1939	1934	1929	1924	TOTAL MEMBERS 1940	1939	1934	1929	1924
CORNELL	1	5	5	3	3	1	72	62	62	67	40	0	0	0	5	6	77	67	65	75	47
RENSSELAER	2	1	0	3	0	0	14	12	12	3	0	29	28	30	26	17	44	40	45	29	17
UNION	3	0	2	0	1	3	0	0	0	1	0	0	0	0	0	0	0	2	0	2	3
KANSAS	4	5	3	3	4	3	13	9	11	16	14	0	0	1	1	2	18	12	15	21	19
YALE	5	18	11	12	7	9	49	53	60	47	21	0	0	0	0	0	67	64	72	54	30
MINNESOTA	6	4	7	6	3	3	83	76	67	41	33	6	6	3	7	4	93	89	76	51	40
NEBRASKA	7	4	0	3	1	3	17	35	17	13	15	0	0	0	0	0	21	35	20	14	18
OHIO STATE	8	22	9	7	11	8	63	44	22	25	37	0	0	0	0	0	85	53	29	36	45
PENN.	9	9	4	12	14	13	3	2	3	7	1	0	0	0	0	0	12	6	15	21	14
BROWN	10	4	3	2			14	13	12			0	0	0			18	16	14		
IOWA	11	7	11	8	5	0	19	24	18	28	8	0	0	0	0	0	26	35	26	33	8
STANFORD	12	4	11	0	9	7	25	27	40	62	49	0	0	0	3	4	29	38	40	74	60
CALIFORNIA	13																				
COLUMBIA	14	3	10	8	5	9	109	80	61	58	55	0	0	0	0	0	112	90	89	63	64
CHICAGO	15	11	4	3	15	9	112	87	83	95	76	0	2	0	0	0	123	93	86	110	85
U. OF MICHIGAN	16	4	3	6	8	2	56	58	53	32	6	0	0	0	0	0	60	61	59	40	8
ILLINOIS	17	4	0	5	13		100	85	60	48		0	1	0	0		104	86	65	61	
CASE	18	2	2	3	2	0	9	10	1	0	1	18	16	16	15	13	29	28	20	17	14
INDIANA UNIV.	19	3	2	0	1	3	7	12	10	14	4	0	0	0	0	0	10	14	10	15	7
MISSOURI-COLUMBIA BRANCH	20	2	0	5	0	1	19	16	12	15	21	0	0	0	0	0	21	18	17	15	22
COLORADO	21	1	3	0	6	1	5	2	5	4	6	0	0	0	0	0	6	5	5	10	7
NORTHWESTERN	22	8	14	4	1	1	15	28	17	20	2	0	0	0	0	0	23	42	21	21	3
SYRACUSE U.	23	7	8	0	2	11	5	2	0	0	5	0	0	0	0	0	12	10	0	2	16
WISCONSIN	24	0	0	0	0	0	114	99	67	33	47	0	0	0	0	0	114	99	67	33	47
U. OF WASH.	25	0	2	4	4	1	6	4	6	7	0	0	0	0	0	0	6	6	10	11	1
WORCESTER POLY.	26	2	1	0	2	2	1	2	3	0	2	0	0	1	8	4	3	3	4	10	8
PURDUE	27	2	2	4	6	2	30	12	14	2	0	0	0	0	0	0	32	14	18	8	2
WASHINGTON UNIVERSITY	28																				
DIST. OF COLUMBIA	29																				
TEXAS	30	1	5	0	0	1	9	8	9	3	2	0	0	0	0	0	10	13	9	3	3
MAYO FOUNDATION	31	10	6	3	10	17	7	16	9	11	6	0	0	0	0	0	17	22	12	21	23
UNIV. OF NORTH CAROLINA	32	8	15	5	5	1	0	0	0	0	0	0	0	0	0	0	8	15	5	5	1
NORTH DAKOTA	33	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0	0	1	1
IOWA STATE	34	4	2	2	6	11	31	36	31	19	25	0	0	0	0	0	35	38	33	25	36
RUTGERS	35	2	2	0	5	1	8	12	14	4	5	0	0	0	0	0	10	14	14	9	6
McGILL	36		5	5	13	24		0	0	0	0		0	0	0	0		5	5	13	24
KENTUCKY	37	1	5	3	5	0	0	0	0	0	0	0	0	0	0	0	1	5	3	5	0
IDAHO	38	2	1	4	1	1	0	0	3	6	0	0	0	0	0	0	2	1	7	7	1
SWARTHMORE	39	4	4	0	2	1	0	0	0	0	0	0	0	0	0	0	4	4	0	2	1
OREGON UNIV.	40	1	5	4	5	4	6	5	4	5	1	0	0	0	1	0	7	10	8	11	5
VIRGINIA	41	0	0	2	2	7	15	19	17	8	6	0	0	0	0	0	15	19	19	10	13
JOHN HOPKINS	42	7	10	19	17	26	17	39	46	37	14	0	0	0	0	0	24	49	65	54	40
CALIFORNIA INST. OF TECHNOLOGY	43	40	44	12	18		0	0	0	0		0	0	0	0		40	44	12	18	
NY UNIV.	44	9	8	7	0		20	16	18	0	0	0	0	0	0		29	24	25	0	
UNIV. OF CINC.	45	3	4	6	8		9	15	8	6	0	0	0	0	0	0	12	19	14	14	
MICHIGAN STATE	46	5	2	1	0		7	6	19	23		0	0	0	0		12	8	20	23	
ARIZONA	47																				
LEHIGH	48	2	2	4	5		0	1	1	0		0	0	0	0		2	3	5	5	
MARYLAND	49	1	5	1	1		15	18	14	5		0	0	0	0		16	23	15	6	
[illegible]	50	2	5	3	8		3	6	0	0		0	0	0	0		5	11	3	8	
[illegible]	51	5	7	10	4		2	2	2	0		0	0	0	0		7	9	12	4	
PENN STATE	52	2	7	7			7	15	19			0	0	0			9	22	26		
OKLAHOMA	53	0	6	5			0	0	0			0	0	0			0	6	6		
WASHINGTON STATE COLLEGE	54	3	0	2			0	0	4			0	0	0			3	0	6		
WYOMING	55	1	4	3			0	0	0			0	0	0			1	4	3		
ROCHESTER	56	7	13	8			17	14	4			0	0	0			24	27	12		
PITTSBURGH	57	8	7	5			2	2	13			0	0	0			10	9	18		
HARVARD	58	6	22	13			33	30	22			0	0	0			39	52	35		
WESTERN RESERVE	59	9	1	2			14	19	11			0	0	0			23	20	13		
PRINCETON	60	3	2	3			32	19	20			0	0	0			35	21	23		
DUKE	61	10	2	9			12	10	8			0	0	0			22	12	17		
U.C.L.A.	62	102					0					0					102				
MASSACHUSETTS INST. OF TECHNOLOGY	63																				
TULANE	64	1	3	34			1	1	0			0	0	0			2	4	34		
WESLEYAN	65	1	2	7			3	0	7			0	0	0			4	2	14		
SMITH	66	2	1				0	0				0	0				2	1			
CARLETON	67	0	1				0	0				0	0				0	1			
BUFFALO	68	0	6				2	0				0	0				2	6			
GEORGE WASHINGTON	69	2	10				5	4				0	0				7	14			
UTAH	70	5	1				0	0				0	0				5	1			
CARNEGIE INSTITUTE OF TECHNOLOGY	71	4	3				1	7				0	0				5	10			
OREGON STATE	72																				
RICE	73																				
MISS STATE	74	5	11				5	5				0	0				10	16			
WELLESLEY	75	2	2				0	0				0	0				2	2			
FLORIDA	76	5	52				0	0				0	0				5	52			
WEST VIRGINIA	77	34	0				2	0				0	0				36	0			
ALABAMA	78	5	7				0	0				0	0				5	7			
VIRGINIA POLY.	79																				
SOUTHERN CAL.	80																				
TOTAL OF ALL CHAPTERS		456	417	290	238	187	1246	1181	1039	766	502	53	53	51	66	50	1755	1651	1380	1070	739

ASSOCIATE

NAME OF CHAPTER	NO.	GRADUATE STUDENTS 1940	1939	1934	1929	1924	UNDERGRADUATE STUDENTS 1940	1939	1934	1929	1924	TOTAL ASSOCIATES 1940	1939	1934	1929	1924
CORNELL	1	10	9	3	0	0	3	1	3	0	0	13	10	6	0	0
RENSSELAER	2	1	10	4	0	0	32	27	26	15	14	33	37	30	15	14
UNION	3	0	0	0	0	0	13	12	12	11	8	13	12	12	11	8
KANSAS	4	0	0	0	0	0	0	1	2	2	0	0	1	2	2	0
YALE	5	3	4	5	0	0	35	25	27	46	20	38	29	32	46	20
MINNESOTA	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEBRASKA	7	23	35	28	18	16	19	26	12	23	26	42	61	40	41	42
OHIO STATE	8	47	46	2	12	11	16	19	32	32	35	63	65	34	44	46
PENN.	9	22	17	18	7	11	5	1	19	16	23	27	18	37	23	34
BROWN	10	30	8	13			22	18	24			52	26	37		
IOWA	11	67	77	42	50	14	6	3	14	22	0	73	80	56	72	14
STANFORD	12	64	36	23	0	0	0	0	0	0	0	64	36	23	0	0
CALIFORNIA	13															
COLUMBIA	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHICAGO	15	0	0	43	79	27	0	0	0	9	5	0	0	43	88	32
U. OF MICHIGAN	16	40	65	65	26	21	22	23	14	11	24	62	88	79	37	45
ILLINOIS	17	133	147	88	66		0	0	0	0		133	147	88	66	
CASE	18															
INDIANA UNIV.	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MISSOURI-COLUMBIA BRANCH	20	3	7	3	10	13	6	6	5	7	6	9	13	8	17	19
COLORADO	21	44	22	16	13	8	1	1	7	3	2	45	23	23	16	10
NORTHWESTERN	22	52	41	40	22	0	3	1	6	3	8	55	42	46	25	8
SYRACUSE U.	23	49	27	18	18		2	0	0	0	0	51	27	18	18	
WISCONSIN	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U. OF WASH.	25	9	5	10	0	0	74	63	29	34	19	83	68	39	34	19
WORCESTER POLY.	26	3	2	0	0	0	18	16	10	17	12	21	18	10	17	12
PURDUE	27	45	39	33	10	2	20	16	30	22	25	65	55	63	32	27
WASHINGTON UNIVERSITY	28															
DIST. OF COLUMBIA	29															
TEXAS	30	35	19	6	9	6	0	0	0	0	0	35	19	6	9	6
MAYO FOUNDATION	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UNIV. OF NORTH CAROLINA	32	20	18	11	22	12	0	0	0	0	0	20	18	11	22	12
NORTH DAKOTA	33	4	2	3	4	10	7	18	4	9	8	11	20	7	13	18
IOWA STATE	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUTGERS	35	16	14	11	16	7	3	5	2	2	10	19	19	13	18	17
McGILL	36		32	5	18	0		1	0	0	0		33	5	18	0
KENTUCKY	37	10	14	7	10	11	1	0	0	0	0	11	14	7	10	11
IDAHO	38	8	6	8	3	2	0	11	6	2	1	8	17	14	5	3
SWARTHMORE	39	0	0	0	0	0	8	5	6	5	2	8	5	6	5	2
OREGON UNIV.	40	5	7	8	22	8	1	2	3	0	0	6	9	11	22	8
VIRGINIA	41	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
JOHN HOPKINS	42	27	25	31	23	15	0	0	0	0	0	27	25	31	23	15
CALIFORNIA INST. OF TECHNOLOGY	43	34	60	9	43		0	0	0	0		34	60	9	43	
NY UNIV.	44	1	0	0	0		0	0	0	0	0	1	0	0	0	
UNIV. OF CINC.	45	16	25	22	11		4	4	6	7		20	29	28	18	
MICHIGAN STATE	46	28	27	0	0		0	0	0	0		28	27	0	0	
ARIZONA	47															
LEHIGH	48	12	5	6	3		0	0	2	0		12	5	8	3	
MARYLAND	49	0	0	0	5		0	0	0	0		0	0	0	5	
[illegible]	50	8	7	4	4		8	7	3	0		16	14	7	4	
[illegible]	51	26	20	2	5		0	0	0	0		26	20	2	5	
PENN STATE	52	9	2	8			0	0	0			9	2	8		
OKLAHOMA	53	24	27	22			7	5	2			31	32	24		
WASHINGTON STATE COLLEGE	54	18	9	9			0	1	0			18	10	9		
WYOMING	55	5	6	3			2	13	0			7	19	3		
ROCHESTER	56	25	23	4			4	3	0			29	26	4		
PITTSBURGH	57	20	15	39			1	2	1			21	17	40		
HARVARD	58	0	0	0			0	0	2			0	0	2		
WESTERN RESERVE	59	0	0	0			0	0	0			0	0	0		
PRINCETON	60	24	22	32			29	26	16			53	48	48		
DUKE	61	11	15	5			0	1	1			11	16	6		
U.C.L.A.	62	37	19	18			4	2	2			41	21	20		
MASSACHUSETTS INST. OF TECHNOLOGY	63															
TULANE	64	5	9	0			0	0	0			5	8	0		
WESLEYAN	65	6	4	9			12	12	8			18	16	17		
SMITH	66	9	8				9	10				18	18			
CARLETON	67	3	0				6	4				9	4			
BUFFALO	68	7	3				0	0				7	3			
GEORGE WASHINGTON	69	13	18				0	0				13	18			
UTAH	70	10	9				0	0				10	9			
CARNEGIE INSTITUTE OF TECHNOLOGY	71	13	13				12	11				25	24			
OREGON STATE	72															
RICE	73															
MISS STATE	74	12	13				0	10				12	23			
WELLESLEY	75	5	1				1	2				6	3			
FLORIDA	76	0	0									0	0			
WEST VIRGINIA	77	0	0				0	0				0	0			
ALABAMA	78	13	6				0	0				13	6			
VIRGINIA POLY.	79															
SOUTHERN CAL.	80															
TOTAL OF ALL CHAPTERS		1164	1100	736	529	194	427	414	336	298	248	1568	1496	1072	827	442

ALUMNI

NAME OF CHAPTER	NO.	GRADUATES OF YOUR INSTITUTION 1940	1939	1934	1929	1924	PROFESSORS, ETC OF NEIGHBORING INSTITUTIONS 1940	1939	1934	1929	1924	FROM WITHIN 5 YRS. / FROM ASSOCIATE [illegible] GRADUATION 1940	1939	1934	1929	1924
CORNELL	1				4	0	0	0	0	0	0	0	0	0	0	0
RENSSELAER	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
UNION	3	0	0	0	0	0	0	1	0	2	0	0	1	0	0	0
KANSAS	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
YALE	5	0	1	0	2	0	0	0	0	0	0	0	0	0	2	0
MINNESOTA	6	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
NEBRASKA	7	1	0	1	2	7	0	0	1	0	0	0	0	0	0	0
OHIO STATE	8	2	0	0	0	0	10	12	13	14	0	0	0	0	0	0
PENN.	9	1	0	0	3	0	3	2	0	2	3	0	1	0		
BROWN	10	0					0					0				
IOWA	11						0	0	0	0	0	5	6	4	2	4
STANFORD	12	1	6	0	1	1	0	0	0	0	0	6	4	0	0	0
CALIFORNIA	13															
COLUMBIA	14	2	5	1	5	0	0	0	0	0	0	0	0	0	0	0
CHICAGO	15															
U. OF MICHIGAN	16	2	1	0	1	0	0	0	0	0	0	3	0	0	0	0
ILLINOIS	17															
CASE	18															
INDIANA UNIV.	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MISSOURI-COLUMBIA BRANCH	20	0	0	0	0	0	0	0	0	0	0		0			
COLORADO	21	8	1	3	1	0	3	0	0	0	0	5	3	4	2	2
NORTHWESTERN	22	3	0	0	0	0	0	0	0	0	0	4	3	1	0	0
SYRACUSE U.	23															
WISCONSIN	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U. OF WASH.	25	0	0	1	3	1	0	0	1	0	0	9	7	5	4	0
WORCESTER POLY.	26	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
PURDUE	27	1	3	1	2	0	0	1	0	0	0	0	0	0	0	0
WASHINGTON UNIVERSITY	28															
DIST. OF COLUMBIA	29															
TEXAS	30	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0
MAYO FOUNDATION	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UNIV. OF NORTH CAROLINA	32	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
NORTH DAKOTA	33	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
IOWA STATE	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RUTGERS	35	0	0	0	0	0	1	3	0	0	0	3	0		0	0
McGILL	36															
KENTUCKY	37	0	1	0	0	0	0	0	0	0	0	0	0	0	0	
IDAHO	38	0	0	0	0	0	0	0	0	0	0	1	0	0	0	
SWARTHMORE	39	0	1	0	0	5	0	0	0	3	0	1	0	0	0	0
OREGON UNIV.	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VIRGINIA	41	0	0	2	0	0	0	0	0	0	0	0	0	0	0	
JOHN HOPKINS	42	1	23	0	5	0	0	0	0	0	0	0	0	0	0	0
CALIFORNIA INST. OF TECHNOLOGY	43	3	0	0	1											
NY UNIV.	44	0	2	0	0		0	0	0	0		0	0	0	0	
UNIV. OF CINC.	45	3	1	1	2		3	0	2	1		0	0	0		
MICHIGAN STATE	46	0	1	1	4		0	0	0	0		0	1	0	0	
ARIZONA	47															
LEHIGH	48	0	0	0	31		0	0	0	0		0	0	0		
MARYLAND	49	2	0	0	0		0	0	0	0		0	0	1	0	
[illegible]	50	1	1	0	0		0	0	4	0		1	0	0	0	
[illegible]	51	2	0	0	0		2	0	0	0		6	2			
PENN STATE	52	0	1	0			0	0	0			9	3	4		
OKLAHOMA	53	0	0	1			0	0	0			0	2	0		
WASHINGTON STATE COLLEGE	54	0	0	0			0	0	0			0	0	0		
WYOMING	55	0	0	0			0	0	0			1	0	0		
ROCHESTER	56	0	0	0			1	0	0			0	0	0		
PITTSBURGH	57	0	0	0			0	0	0			0	0	0		
HARVARD	58	1	0	1												
WESTERN RESERVE	59	0	0	0			1	1	0			0	0	0		
PRINCETON	60	4	1	2			0	0	0			0	0	0		
DUKE	61	0	1	1			0	0	0			0	0	0		
U.C.L.A.	62	2	0	0			0	0	0			2	0	0		
MASSACHUSETTS INST. OF TECHNOLOGY	63															
TULANE	64	0	0	5												
WESLEYAN	65	0	1	0			0	0	0			0	0	0		
SMITH	66	0	0				0	0				0	0			
CARLETON	67	0	0				0	0				0	0			
BUFFALO	68	0	1				0	2				0	1			
GEORGE WASHINGTON	69	0	0				0	0				0	0			
UTAH	70	2	0				3	1				0	0			
CARNEGIE INSTITUTE OF TECHNOLOGY	71	0	3				0	0				0	0			
OREGON STATE	72															
RICE	73															
MISS STATE	74	0	0				0	0				0	0			
WELLESLEY	75	0	0				0	0				0	0			
FLORIDA	76	0	0				0	0				0	0			
WEST VIRGINIA	77	10	0				0	0				0	0			
ALABAMA	78	0	0				0	0				0	0			
VIRGINIA POLY.	79															
SOUTHERN CAL.	80															

Y OF MEMBERSHIP STRUCTURE

ASSOCIATE											ALUMNI																					
S	UNDERGRADUATE STUDENTS					TOTAL ASSOCIATES					GRADUATES OF YOUR INSTITUTION					PROFESSORS, ETC OF NEIGHBORING INSTITUTIONS					FROM FROM ASSOCIATE - WITHIN 5 YRS AFTER GRADUATION					FROM FROM ASSOCIATE - 5 YRS AFTER GRADUATION					
1924	1940	1939	1934	1929	1924	1940	1939	1934	1929	1924	1940	1939	1934	1929	1924	1940	1939	1934	1929	1924	1940	1939	1934	1929	1924	1940	1939	1934	1929	1924	1940
0	3	1	3	0	0	13	10	6	0	0	1	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	32	27	26	15	14	33	37	30	15	14	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	3
0	13	12	12	11	8	13	12	12	11	8	0	0	0	0	0	0	1	0	2	0	0	1	0	0	0	0	1	0	1	0	0
0	0	1	2	2	0	0	1	2	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	35	25	27	46	20	38	29	32	46	20	0	1	0	2	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	19	26	12	23	26	42	61	40	41	42	1	0	1	2	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
11	16	19	32	32	35	63	65	34	44	46	2	0	0	0	0	10	12	13	14	0	0	0	0	0	0	0	0	0	0	0	12
11	5	1	19	16	23	27	18	37	23	34	1	0	0	3	0	3	2	0	2	3	0	1	0	1	1	0	1	1	0	0	4
	22	18	24			52	26	37			0					0					0					0		3			
14	6	3	14	22	0	73	80	56	72	14						0	0	0	0	0	5	6	4	2	4	1	1	0	0	0	6
0	0	0	0	0	0	64	36	23	0	0	1	6	0	1	1	0	0	0	0	0	6	4	0	0	0	0	0	0	0	0	7
0	0	0	0	0	0	0	0	0	0	0	2	5	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
27	0	0	0	9	5	0	0	43	88	32																					
21	22	23	14	11	24	62	88	79	37	45	2	1	0	1	0	0	0	0	0	0	3	0	0	0	0	1	2	0	0	0	6
	0	0	0	0		133	147	88	66																						0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	6	6	5	7	6	9	13	8	17	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	1	7	3	2	45	23	23	16	10	8	1	3	1	0	3	0	0	0	0	5	3	4	2	2	0	0	0	0	0	16
0	3	1	6	3	8	55	42	46	25	8	3	0	0	0	0	0	0	0	0	0	4	3	1	0	0	1	0	0	0	0	8
	2	0	0	0	0	51	27	18	18																						
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	74	63	29	34	19	83	68	39	34	19	0	0	1	3	1	0	0	1	0	0	9	7	15	4	0	1	1	0	0	0	10
0	18	16	10	17	12	21	18	10	17	12	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	20	16	30	22	25	65	55	63	32	27	1	3	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6	0	0	0	0	0	35	19	6	9	6	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	20	18	11	22	12	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
10	7	18	4	9	8	11	20	7	13	18	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	3	5	2	2	10	19	19	13	18	17	0	0	0	0	0	1	3	0	0	0	3	0	1	0	0	0	0	0	0	0	3
0		1	0	0	0		33	5	18	0																					
11	1	0	0	0	0	11	14	7	10	11	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	11	6	2	1	8	17	14	5	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
0	8	5	6	5	2	8	5	6	5	2	0	1	0	0	5	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	
8	1	2	3	0	0	6	9	11	22	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	1	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	0	0	0	0	0	27	25	31	23	15	1	23	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	0	0	0	0		34	60	9	43		3	0	0	1																	3
	0	0	0	0		1	0	0	0		0	2	0	0		0	0	0	0		0	0	0	0		0	0	0	0	0	0
	2	4	6	7		20	29	28	18		3	1	1	2		3	0	2	1		0	0	0	0		0	2	0	0	0	0
	0	0	0	0		28	27	0	0		0	0	0	4		0	0	0	0		0	1	0	0		0	0	0	0		
	0	0	2	0		12	5	8	3		0	0	0	31		0	0	0	0		0	0	0	0		0	0	0	0		
	0	0	0	0		0	0	0	5		2	0	0	0		0	0	0	0		0	0	1	0		0	0	0	0		
	8	7	3	0		16	14	7	4		1	1	0	0		0	0	4	0		1	0	0	0		0	0	0	0		
	0	0	0	0		26	20	2	5		2	0	0	0		2	0	0	0		6	2	0	0		0	0	0	0		1
	0	0	0			9	2	8			0	1	0			0	0	0			9	3	4			0	0	0			
	7	5	2			31	32	24			0	0	1			0	0	0			0	2	0			4	1	0			
	0	1	0			18	10	9			0	0	0			0	0	0			0	0	0			0	0	0			
	2	13	0			7	19	3			0	0	0			0	0	0			1	0	0			1	0	0			
	4	3	0			29	26	4			0	0	0			1	0	0			0	0	0			0	0	0			
	1	2	1			21	17	40			0	0	0			0	0	0			0	0	0								
	0	0	2			0	0	2			1	0	1																		
	0	0	0			0	0	0			0	0	0			1	1	0			0	0	0			0	0	0			
	29	26	16			53	48	48			4	1	2			0	0	0			0	0	0			0	0	0			
	0	1	1			11	16	6			0	1	1			0	0	0			0	0	0			0	0	0			
	4	2	2			41	21	20			2	0	0			0	0	0			2	0	0			0	0	0			
	0	0	0			5	0	0			0	0	5																		
	12	12	8			18	16	17			0	1	0			0	0	0			0	0	0			0	0	0			
	9	10				18	18				0	0				0	0				0	0				0	0				
	6	4				9	4				0	0				0	0				0	0				0	0				
	0	0				7	3				0	1				0	2				0	1				0	0				
	0	0				13	18				0	0				0	0				0	0				0	0				
	0	0				10	9				2	0				3	1				0	0				0	0				
	12	11				25	24				0	3				0	0				0	0				0	0				
	0	10				12	23				0	0				0	0				0	0				0	0				
	1	2				6	3				0	0				0	0				0	0				0	0				
						0	0				0	0				0	0				0	0				0	0				
	0	0				0	0				10	0				0	0				0	0				0	0				
	0	0				13	6				0	0				0	0				0	0				0	0				
194	427	414	336	298	248	1568	1496	1072	827	442																					

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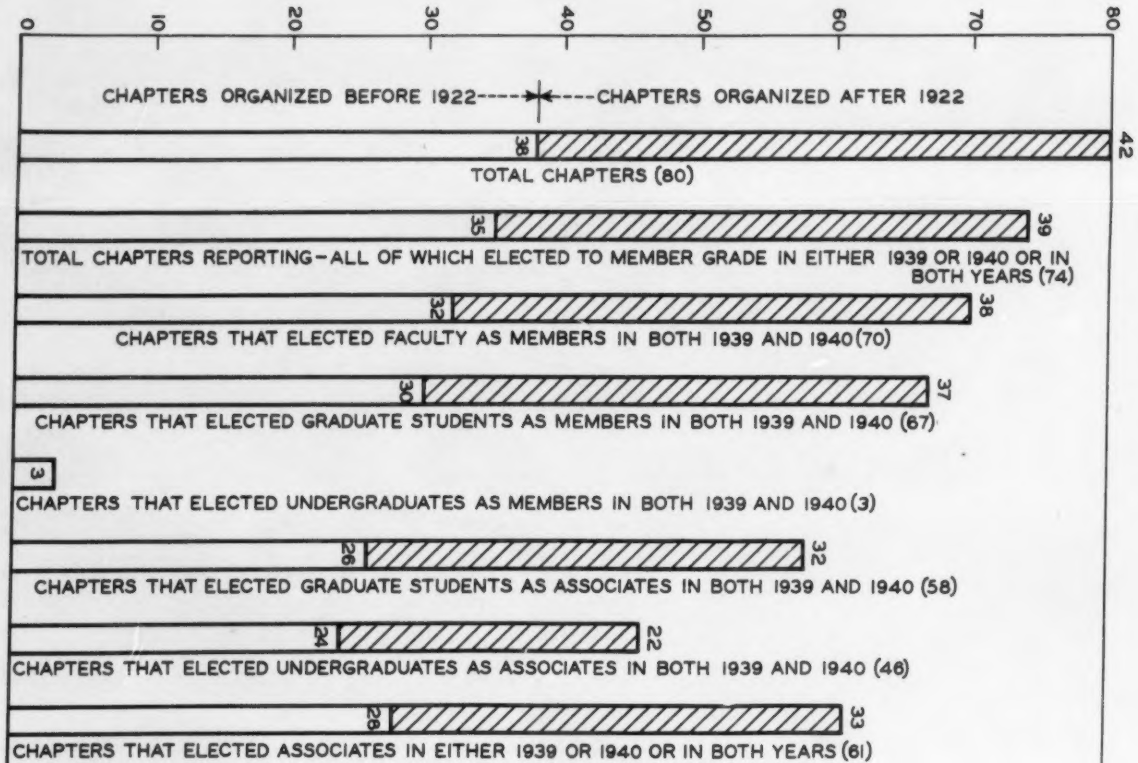
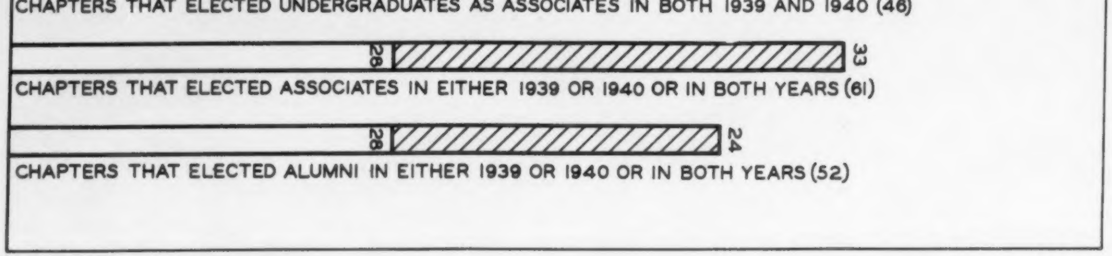
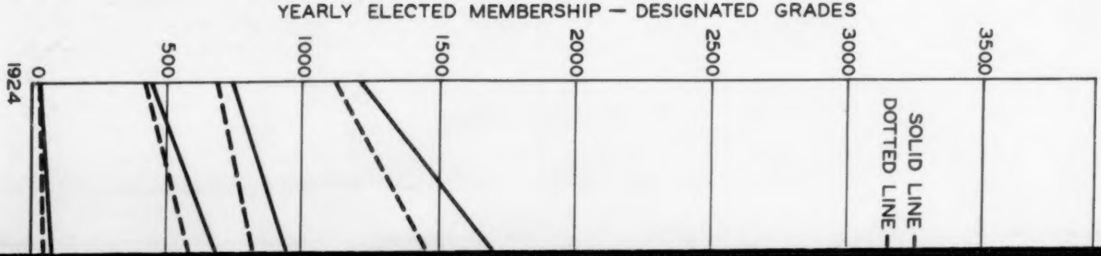
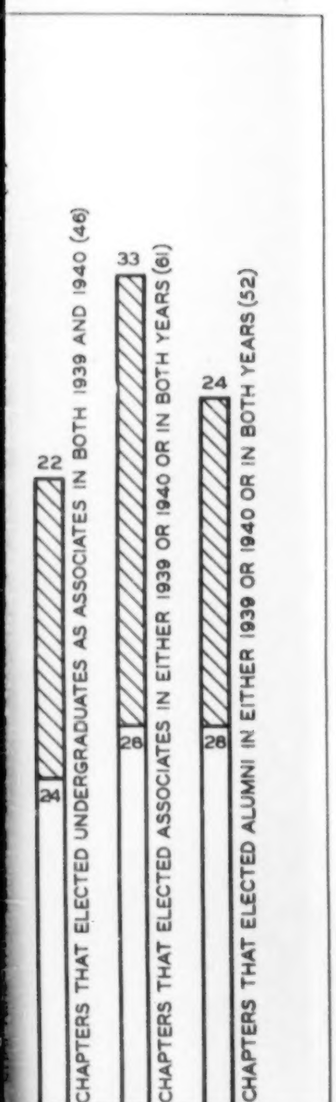
… ASSOCIATE- …R GRADUATION			TOTAL ALUMNI					GRAND TOTAL MEMBERS, ASSOCIATES AND ALUMNI					TOTAL UNDERGRAD STUDENTS IN INSTITUTION AT CLOSE OF THE 1940 SCHOOL YEAR	TOTAL GRADUATE STUDENTS IN INSTITUTION AT CLOSE OF 1940 SCHOOL YEAR	TOTAL GRAD STUDENTS IN SCIENCE ELIGIBLE FOR SIGMA XI AT CLOSE OF 1940 SCHOOL YEAR	TOTAL SIGMA XI MEMBERSHIP AT CLOSE OF THE 1940 SCHOOL YEAR	TOTAL SIGMA XI ASSOCIATES AT CLOSE OF THE 1940 SCHOOL YEAR	NO. OF ASSOCIATES ELECTED IN THE PAST 5 YEARS	NO. OF THESE ASSOCIATES PROMOTED TO MEMBER	DO YOU COLLECT DUES OF [illegible] MEMBERS & ASSOCIATES NOT NOW ON THE STAFF OR ACTIVE AT YOUR INSTITUTION?	PLEASE DESCRIBE THE SCHEME OR ATTACH CIRCULAR MATTER OR LETTERS SENT TO YOUR FORMER MEMBERS	DEPTS. SCHOOLS OR SUB DIVISIONS REQUIRING [illegible] OF THESIS FOR UNDERGRAD. [illegible]
1934	1929	1924	1940	1939	1934	1929	1924	1940	1939	1934	1929	1924										
0	0	0	1	1	1	4	0	91	78	72	79	47	5671	1000	686	431	49	47	8	YES	NONE	NONE
0	0	0	3	0	0	2	0	80	77	75	46	31	1492	53	53	95	12	272	105	NO	NONE	YES- [illegible]
0	1	0	0	3	0	3	0	13	17	12	16	11	829	3	3	31	0	55	0	NO		CHEMISTRY & PHYSICS
0	0	0	0	0	0	1	0	18	13	17	24	19	4394	473	174	139	6	6	2		NONE	NONE
0	0	0	0	3	2	2	0	105	96	106	102	50	3111	2633	611	148	66	159	8	NO		NONE
0	0	0	0	2	1	0	0	93	91	77	51	40	11982	1897	280	600	0	0	0	RARELY		NONE
0	0	0	1	0	2	2	7	64	96	62	57	67	5982	380	154	163	94	221	[illegible]	NO		NONE
0	0	0	12	12	13	14	0	160	130	76	94	91	11761	1255	525	435	181			YES		[illegible] DEPTS
1	0	0	4	4	1	6	4	43	28	53	50	52	4350	1350	485	319	150	100	4	YES		
3					3			70	42	54			1913	346		101	88	205				YES- LISTED
0	0	0	6	8	4	2	4	105	123	86	107	26	5388	1373	623	207	166	374	53	NO	NONE	NONE
0	0	0	7	10	0	1	0	100	94	63	75	60	3460	1782	565	242	119	195	24	YES		NONE
0	0	0	2	5	1	5	0	114	95	90	68	64	2916	9916	1048	482	0	0		NO		
								123	93	129	198	117	4325	6312	1217	401	40	167	91	YES		NONE
0	0	0	6	3	0	1	0	128	152	138	78	53	9928	3083	765	421	274	390	145	YES	NONE	NONE
			0	0	0	0		237	233	153	127		11712	1523		451	261			NO	NONE	
								29	28	20	17	14	911	87	87	63	0	0	0	NO		YES- LISTED
0	0	0	0	0	0	0	0	10	14	10	15	7	5366	448	12	135	0	0	0	YES		NONE
0	0	0	0	0	0	0	0	30	31	25	32	41	5306	680				36	4	YES		NONE
0	0	0	16	4	7	3	2	67	32	35	29	19	4090	411	264	170	99	126	19	YES		NONE
0	0	0	8	3	1	0	0	86	87	68	46	11	18000	1741	374	225	161	198	45	YES		NONE
								63	37	18	20	16	5185	640	169	130	60	162	2	NO	NONE	NONE
0	0	0	0	0	0	0	0	114	99	67	33	47	10046	1472		477	0	0	0	NO		YES- LISTED
0	0	0	10	8	17	7	1	99	82	66	52	21	9240	985		135	150	386	81	NO	NONE	M.E
0	0	0	0	0	0	4	0	24	21	14	31	20	645	18	18	46	20	100	5	NO		YES- LISTED
0	0	0	1	4	1	2	0	98	73	82	42	29	6614	490	490	170	63	293	45	NO		
0	0	0	0	2	0	0	1	45	34	15	12	10	10157	918	150	114	62	128	23	ONLY IF THEY DESIRE	[illegible]	NONE
0	0	0	0	0	0	0	0	17	22	12	21	23	335		17	164	0	0		NO	NONE	NONE
0	0	0	1	0	0	0	1	29	33	16	27	14	3571	473	127	98 (TOGETHER)		91	10	NO		
0	0	0	1	0	0	0	2	13	20	7	14	21	1782	178		26	16	51	1	NO	NONE	ENG'G
0	0	0	0	0	0	0	0	35	38	33	25	36	6306	669	494	211	0	0		NO		M.E.
0	0	0	3	3	1	0	0	32	36	28	27	23	2997	177	25	149	68	115	21	YES		
									38	10	31	24	2442	232	149	147	107	116	10	YES		NONE
0	0	0	0	1	0	0	0	12	20	10	15	11	4395	1541	104	78	21	64	0	NO		NONE
0	0	0	1	0	0	0	0	11	18	21	12	4	2856	156	72	78	5	79	6	NO		ONLY COLLEGE OF AGRICULTURE
0	0	0	1	1	0	3	5	13	10	6	10	8	737	0	0	111	72	36	3	YES		NONE
0	0	0	0	0	0	0	0	13	19	19	33	13	3968	236	268	69	24	46	4	NO		ONLY BACH. DEGREE WITH HONORS
0	0	0	0	0	2	0	0	16	19	21	10	13	1686	273	97	321	4	1	0	NO		NONE
0	0	0	1	23	0	5	0	52	97	96	82	55	4442	516		280	65	184	70	YES		NONE
			3	0	0	1		77	104	21	62		589	269		166	98			NO		
0	0	0	0	2	0	0	0	30	26	26	0	0	27559	1695	565	180	4	5	3	YES	[illegible]	ONLY FOR HONOR STUD'S
0	0	0	6	3	3	3	0	38	51	45	36	0	4937	626	146	170	66	86	43	YES		YES- LISTED
0	0		0	0	0	4		40	35	20	27		6586	710	81	138	32	65	0	NO	NONE	CE
													2714	192	63	76	7	54	8	RARELY	NONE	NONE
0	0		0	0	0	31		14	8	13	39		1800	168	94	83	17	21	3	NO		NONE
0	0		2	0	1	0		18	23	16	11		3131	384	226	103	0	0	0	YES		CIVIL AND MECH. ENG.
0	0		2	1	4	0		23	26	14	12		4420	490	424	128	36	65	1	RARELY		
0	0		10	2	0	0		43	31	14	9		1061	170		163	89	60	12	YES		NONE
0			9	4	4			27	28	38			7100	525	308			50	12	YES		
0			4	3	1			35	41	30			6873	563	132	81	30					
0			0	0	0			21	10	15			3497	230		83	31	57	2	ONLY IF OFFERED		
0			2	0	0			10	23	6			1847	68	32	66	13	40	0	YES		NONE
0			1	0	0			54	53	16			1075	453	140	147	67	102	47	YES		ONLY DEGREES WITH DISTINCTION [illegible]
			0	0	0			31	26	58			7827	3911		135	106	83	5	YES		ENG'G
			1	0	1			40	52	38			3556	4551	1215	955	17	3	1	YES		ONLY DEGREES WITH HONORS
0			1	1	0			24	21	13			8014	2591	18	213	0	0	0	YES		NONE
0			4	1	2			92	70	73			2415	299	136	173	102	306	140	YES		YES-ALL DEPT'S
0			0	1	1			33	29	24			2685	784	482	112	14	53	27	NO		NONE
0			4	0	0			147	21	20			8696	1146	247	102	41	130		YES		NONE
			0	0	5			7	13	39			9529	466	72	51	29	52	5	NO		YES
0			0	1	0			22	19	31			742	27	15	31	21	74	5	NO	NONE	
			0	0				20	19				1981	104		54	23	73		NO	NONE	NONE
			0	0				9	5				849	19	5	20	9	9	0	NO		NONE
			0	4				9	13				4622	311	6	70	16	27	2	NO	NONE	YES- LISTED
			0	0				20	32				4800	2800	275	126	47	47	0	NO	NONE	NONE
			5	1				20	11				4291	178	50	71	10	46	2	NO		ENG'G
			0	3				30	37				2260	83	61	88	46	82	8	NO	NONE	METALLURGY ENG'G
			0	0				22	39				1180	153	33	77	15	46	1	NO	NONE	NONE
			0	0				8	5				1457	54	15	39	12	15	1	YES		NONE
			0	0				5	52				3260	196	0	77	0	0	0	NO		NONE
			10	0				46	0				3002	254	90	89	0	0	0	NO		
			0	0				18	13				5030	473	18	48	20	19	0	NO		
													2880	239	0	39	0	0	0	NO		[illegible]
			149	127	79	106	27	3465	3292	2531	2003	1268	309779	64276	14222	10871	3433	5755	1101			

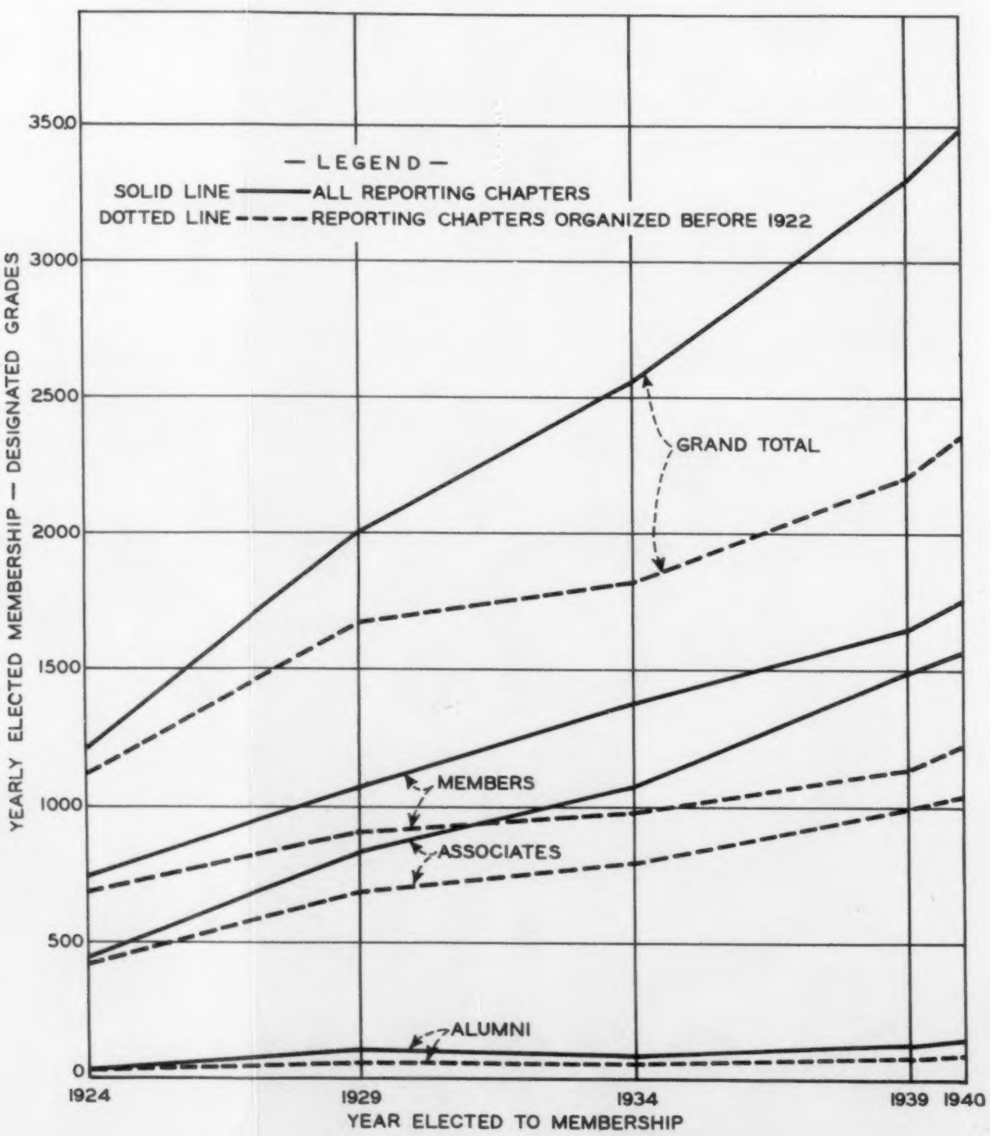


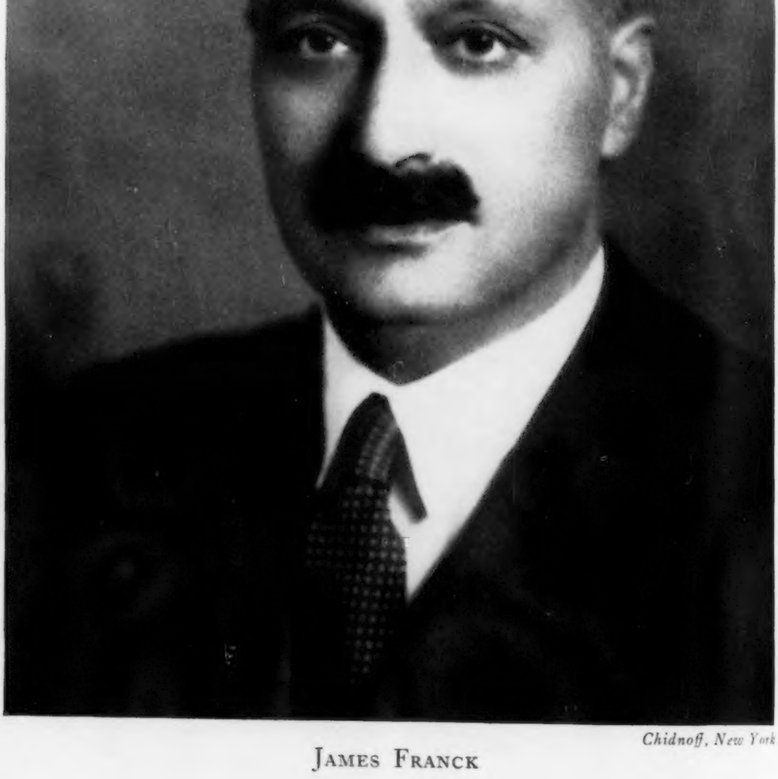
0
10
20
30
40
50
60
70
80
CHAPTERS ORGANIZED BEFORE 1922
CHAPTERS ORGANIZED AFTER 1922
38
42
TOTAL CHAPTERS (80)
35
39
TOTAL CHAPTERS REPORTING–ALL OF WHICH ELECTED TO MEMBER GRADE IN EITHER 1939 OR 1940 OR IN BOTH YEARS (74)
32
38
CHAPTERS THAT ELECTED FACULTY AS MEMBERS IN BOTH 1939 AND 1940 (70)
30
37
CHAPTERS THAT ELECTED GRADUATE STUDENTS AS MEMBERS IN BOTH 1939 AND 1940 (67)
3
CHAPTERS THAT ELECTED UNDERGRADUATES AS MEMBERS IN BOTH 1939 AND 1940 (3)
26
32
CHAPTERS THAT ELECTED GRADUATE STUDENTS AS ASSOCIATES IN BOTH 1939 AND 1940 (58)
24
22
CHAPTERS THAT ELECTED UNDERGRADUATES AS ASSOCIATES IN BOTH 1939 AND 1940 (46)
28
33
CHAPTERS THAT ELECTED ASSOCIATES IN EITHER 1939 OR 1940 OR IN BOTH YEARS (61)


CHAPTERS THAT ELECTED UNDERGRADUATES AS ASSOCIATES IN BOTH 1939 AND 1940 (46)
28
33
CHAPTERS THAT ELECTED ASSOCIATES IN EITHER 1939 OR 1940 OR IN BOTH YEARS (61)
28
24
CHAPTERS THAT ELECTED ALUMNI IN EITHER 1939 OR 1940 OR IN BOTH YEARS (52)


YEARLY ELECTED MEMBERSHIP — DESIGNATED GRADES
0
500
1000
1500
2000
2500
3000
3500
1924
SOLID LINE —
DOTTED LINE —


22
24
CHAPTERS THAT ELECTED UNDERGRADUATES AS ASSOCIATES IN BOTH 1939 AND 1940 (46)
33
28
CHAPTERS THAT ELECTED ASSOCIATES IN EITHER 1939 OR 1940 OR IN BOTH YEARS (61)
24
28
CHAPTERS THAT ELECTED ALUMNI IN EITHER 1939 OR 1940 OR IN BOTH YEARS (52)


— LEGEND —
SOLID LINE —— ALL REPORTING CHAPTERS
DOTTED LINE - - - REPORTING CHAPTERS ORGANIZED BEFORE 1922
GRAND TOTAL
MEMBERS
ASSOCIATES
ALUMNI
YEARLY ELECTED MEMBERSHIP — DESIGNATED GRADES
3500
3000
2500
2000
1500
1000
500
0
1924
1929
1934
1939
1940
YEAR ELECTED TO MEMBERSHIP



Chidnoff, New York

JAMES FRANCK